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# SOME ASPECTS OF FOOD REFRIGERATION AND FREEZING



An FAO Study Edited by DONALD K. TRESSLER
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Agriculture Division, Food and Agriculture
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# Preface

Proper refrigeration greatly reduces losses of perishable foods during handling, storage, transportation, and marketing. Providing adequate refrigeration is the only available method of preserving the quality and the nutritive value of many fresh foods. Recognizing the importance of refrigeration in the preservation of fruit, vegetables, dairy, and other food products, and the interest of many European countries in further developments in this field, FAO held a meeting in Copenhagen, Denmark, 11-23 October 1948, to which all European countries were invited to send their specialists in food refrigeration and freezing to exchange information on new developments in these fields. Approximately 100 workers were in attendance from:

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|---|---|---|
| Austria | France | The Netherlands |
| Czechoslovakia | Greece | Norway |
| Denmark | Iceland | Poland |
| Finland | Italy | Sweden |
| | | United Kingdom |

A number of workers were invited to prepare papers for presentation at the meeting, and these papers have been used as the main source of material for this publication. In order to avoid duplication and to fill in certain gaps in the material, the papers are not being reproduced in their original form. However, the material has been redrafted and rearranged to provide a comprehensive outline of current knowledge in various fields of food refrigeration and freezing, which has particular application in Europe, and which is in general applicable to all parts of the world.

The technical papers presented at the meeting and their authors, were as follows:

Principles of Refrigeration .......... Donald K. Tressler (FAO)

Theory about Production of Cold .......... S. A. Andersen (Denmark)

Ice—Production and Use .......... Erik Holten (Denmark)

Household Refrigerators, Home Freezers and Locker Plants .. S. Mansted (Denmark)

Construction of Cold Storage Plans:
I. Practical Considerations .......... A. G. Clausen (U.K.)

Construction of Cold Storage Plants:
II. Problems .......... Thore M. Elfving (Sweden)

Refrigerating Machinery:
I. Compressors for Refrigeration .......... O. Kramhøft (Denmark)

Refrigerating Machinery:
II. Condensers, Evaporators, Etc. .......... Gustav Lorentzen (Norway)

| | |
|---|---|
| Methods and Apparatus for Commercial Freezing | Donald K. Tressler (FAO) |
| Packaging Materials and Machinery | Mog. Kondrup (Denmark) |
| Judging Flavor, Color, and Texture of Foods | Mog. Kondrup (Denmark) |
| Chilled and Frozen Dairy Products | Sigurd Nielsen (Denmark) |
| Chilled and Frozen Lean Fish | Olav Notevarp (Norway) |
| Chilled and Frozen Fatty Fish | A. Banks (U.K.) |
| Refrigeration of Fruits and Vegetables at Temperatures above Freezing | G. Borgström (Sweden) |
| Refrigerated Gas-Storage of Fruit | W. Hugh Smith (U.K.) |
| Frozen Fruits and Vegetables | Paul Clement (France) |
| The Helgerud Process | Odd Sjetne (Norway) |
| Meat and Meat Products | J. A. Brewster (U.K.) |
| Chilled and Frozen Poultry | D. K. Tressler (FAO) |
| Chilling and Freezing Poultry in Denmark | A. Thøsing Jørgensen (Denmark) |
| Miscellaneous Frozen Products | D. K. Tressler (FAO) |
| Transportation of Chilled and Frozen Foods in Europe | H. J. Jerne (Denmark) |
| Marketing Frozen Foods in Europe | Nils Jangaard (FAO) |

Material has been freely used from these papers. In some cases virtually the entire paper has been used, while in others, largely for the sake of brevity or to avoid duplication, only a portion has been used. In still others the material has been largely rewritten to make it fit in with related parts of the publication.

In addition to the material presented in formal papers at the meeting, there were many informal contributions given in discussion and, while it is not possible to indicate these contributions specifically, the following workers, other than those who prepared papers, participated in the meeting and their contributions to the discussion are gratefully acknowledged:

V. E. Albertsen (Denmark)

Frants Bergh (Denmark)
P. P. Bischoff (Denmark)
E. Bjørn (Denmark)
A. G. Blom (Denmark)
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Chr. Christiansen (Denmark)
W. Cieglewicz (Poland)

I. Dalkiaer (Denmark)
Bent. Dehlholm (Denmark)
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This opportunity is taken to gratefully acknowledge the special contribution of F. Bramsnaes, Director of the Technological Laboratory of the Ministry of Fisheries in Denmark. Mr. Bramsnaes' patience and skill in the difficult task of making the local arrangements for the meeting and in assisting with certain of the international arrangements were in large measure responsible for its success.

Special thanks should also be given to Prof. Mogens Kondrup, of the Danish Refrigeration Research Laboratory, who conducted a special exhibition and demonstration of packaging materials and frozen foods in his laboratory. Many of the products demonstrated had been obtained in the United States especially for the Refrigeration Meeting and transported by air in a special plastic frozen food shipping container provided by the R. H. Bishop Company, Champaign, Illinois, U.S.A.

An understanding of some of the more common terms used by the food technologist and refrigerating engineer in discussing the refrigeration of foods should aid in understanding this report.

The term "fresh" when used in reference to perishable foods is often misunderstood. To the technologist, "fresh" foods are those which have not been placed in a cold-storage warehouse or preserved by any other method, such as canning or dehydration.

"Cold-stored foods" or "cold-storage goods" are perishable foods which have been held in a cold-storage warehouse at temperatures above —2° C. There are exceptions to these definitions: e.g., meats, both fresh and cured, are almost universally kept in refrigerated warehouses and unless packaged before freezing are not considered cold stored. Frozen poultry, which of course has been held at temperatures far below —2° C., is also called cold stored if thawed before sale.

No wholly satisfactory definition of "quick freezing" or "quick frozen" has ever been offered. In the United States and Canada, all

frozen fruits, vegetables, fish, shellfish, meat, poultry, and cooked foods that are offered for sale either at retail in small packages or to hotels, restaurants, and institutions in somewhat larger packages weighing, e.g., 5 or 10 pounds (2.27 to 4.54 kg.) each, are termed "quick frozen" regardless of the method of freezing employed.

In England the official definitions are as follows:

(a) A quick frozen fish shall be considered to be one, no part of which took more than two hours to cool from 0° to —5° C.

(b) A quick freezing plant shall be considered to be one that is capable of fulfilling the definition mentioned in (a) when dealing with whole fish or with regularly shaped packs or packages of fillets in molds, cardboard boxes, or normal light wrappings (cellulose film), waxed papers, etc.

In all countries, products which are frozen in large containers or in bulk for processing are termed simply "frozen foods," although, in a broader sense, "quick frozen foods" are also frozen foods.

In the United States and Canada, fish and fishery products and shellfish frozen either individually or in pans containing about 30 lb. (13.5 kg.) on refrigerated coils (pipes) maintained at —25° C. or lower, are termed "sharp-frozen" by the trade. Large quantities of fruits, especially berries, are frozen in barrels and large tin cans for use in making jelly, jam, and preserves, ice cream, ice-cream toppings, confectionery, soft drinks, pies, and other baked goods, etc. These products are termed "cold pack" or "frozen pack" regardless of the temperature or method of freezing employed.

The Food and Agriculture Organization of the United Nations is indebted to Donald K. Tressler for his work in editing the material presented at the Copenhagen meeting, and for supplying a great deal of additional information on recent developments in food refrigeration and freezing which are incorporated in this publication. Dr. Tressler carried out this work during two periods in which he served as consultant on food refrigeration and freezing in the Agriculture Division of FAO. During the first period he assisted in the preparation for and participated in the Copenhagen meeting, thus becoming thoroughly familiar with the subject matter presented at the meeting by European specialists. His services were again secured to edit the material and to prepare it for publication as here presented.

Special thanks are also due to Mogens Jul, Chief Technologist, Fisheries Division of FAO, for assistance in organizing the Copenhagen meeting.

RALPH W. PHILLIPS,
*Deputy Director, Agriculture Division*

# Contents

# I. Principles of Refrigeration[1]

IF PERISHABLE foods are transported and marketed without refrigeration, their distribution is not only very limited, but great losses occur because of spoilage. Fruit and vegetable losses often run as high as 50 percent in warm weather. Refrigeration at temperatures approximating 0° C. greatly reduces these losses; and prompt freezing, followed by storage at —18° C., completely eliminates them.

Refrigeration of perishable foods has several advantages in addition to the reduction of spoilage losses. Foods that are properly refrigerated during storage, transportation, and marketing reach the consumer in far better condition and consequently command a much higher price. Properly refrigerated foods not only look better, they *are* better because they are sweeter, have a better flavor, and retain a much higher content of vitamin C and other easily oxidizable vitamins. Proper refrigeration makes possible the transportation of perishables for great distances and their sale in markets that would be otherwise unavailable.

Further, it eliminates the necessity of selling perishable foods on glutted markets. Under refrigeration, they can be held until the price improves, or they can be moved into a better market.

It is evident, therefore, that more general use of adequate refrigeration will do much to increase and improve the world's food supply by: (1) reducing spoilage of food, (2) preventing loss of vitamins and other nutrients, and (3) making a greater variety of wholesome foods available everywhere.

The need for refrigeration is far more general than is popularly believed. Meat, fish, shellfish, poultry and eggs, dairy products, shortening, yeast, fruits, and vegetables are generally recognized as

[1]Based on a paper presented by Donald K. Tressler.

perishable foods which must be refrigerated during transportation and storage. Many other foods which are not commonly considered perishable slowly deteriorate unless they are kept cool, and should be refrigerated if they are stored for more than a few weeks. Some of the more important of the semiperishable foods include dried and dehydrated vegetables and fruits, many nuts, canned and concentrated orange juice, and condensed milk.

In order to understand why certain foods must be given special treatment and why others should be held at especially low temperatures, it is necessary to know something of the principles underlying food preservation by temperature control.

The principal causes of food spoilage are:

(1) The growth of micro-organisms (yeast, molds, and bacteria);
(2) The life processes of the foods themselves (particularly fruits and vegetables);
(3) Enzyme actions;
(4) Physical changes such as desiccation; and
(5) Chemical changes such as oxidation.

After fruits and vegetables are harvested they continue to live during cold storage. But when freezing kills them, there is no need to worry further about respiration and transpiration as such. However, consideration must be given to the actions of the enzymes in the tissues, which are largely disrupted by freezing. It is sometimes said that ultrarapid freezing causes little breakdown in tissues. It is true that the more rapid the freezing, the less the breakdown of the tissues, but even with the least possible breakdown of tissues, sufficient change occurs in them to permit abnormal enzyme actions. In frozen food the enzyme actions are not simple respiration, but the active enzymes slowly destroy the tissues. This is called autolysis. Very low temperatures (e.g., $-10^\circ$ C.) are necessary to check these enzyme actions.

Then there are physical actions, the chief of which is desiccation. This occurs mostly on the surface of foods. Only after it has become very serious does the interior of the food become desiccated or dehydrated. By that time the food is in very poor condition. It is not spoiled by bacteria, but it is no longer a good salable product as the flavor is affected and the product is tough.

Some chemical changes are closely associated with enzymic changes, others occur independently. For example, in living tissues and in meats, poultry, fish, etc., which have not been cooked, oxidation and hydrolysis of fats are accelerated by enzyme actions. In fish, shellfish, and similar products, oxidation of the fats, particularly (but not solely) unsaturated fats, occurs about as fast, or in some instances

faster after cooking (in the absence of enzymes) than it does in products that have not been heated.

Another objectionable type of chemical action (or, more probably, a combination of physical and chemical actions) in frozen foods is the denaturation of proteins. When foods are frozen, the water separates as pure water ice and not as a simple solution of the natural cell contents. The faster the rate of freezing, the less the water has an opportunity to crystallize as pure ice; consequently, the less the proteins are denatured or dehydrated. Regardless of the rate of freezing, however, if frozen fish are held under refrigeration for a long time the proteins slowly become denatured. Fish held in storage for four or five years, even though frozen with great rapidity, become very tough, and do not become tender even when they are boiled for some time.

If fish are thawed before cooking, some of the water exudes, leaks, or drips from the tissues. The same thing is true of meat, especially nonfatty meat such as beef. In lean meat, (particularly thinly cut slices like steaks) the thinner the steaks are cut the greater the proportion of drip to the weight of the meat being frozen. Very rapidly frozen meat, when thawed immediately after freezing, has very little drip or leakage, but frozen meat held for several months has a considerable amount of leakage. As the liquid drips out it carries with it the juices of the meat or fish, removing much of the flavor and some of the nutrients.

Molds are particularly active in products held above freezing temperature. The closer to freezing, the less the growth of microorganisms. Further, when products are held closer to freezing they respire and transpire less, and the loss of sugar and water is less; consequently, the loss of weight and sweetness is minimized.

Similarly, the chemical and physical actions in cool storage are retarded by low temperatures, and, in general, the lower the temperature the less are the effects of cool storage. There are many exceptions, of course, especially with tropical fruits. Bananas are best preserved at about 15° C. Many other tropical fruits are best preserved between 10° and 15° C. On the other hand, most of the fruits grown in the temperature regions, for example, apples and pears, are best held at about —1.5° C.—below the freezing point of water—but the products do not freeze because they contain sugar. Apples keep nearly twice as long at —1.5° C. as at +2° C.

Storage at temperatures below freezing preserves food more effectively than storage at temperatures above freezing. Ordinarily, storage above freezing keeps fruits and vegetables for a few weeks or at most a few months. Storage below freezing keeps vegetables in good condition for at least a year. Perhaps such a long storage period is not necessary. However, if little or no change occurs in a food

in 12-months' storage in an experimental freezer, it is certain that, under commercial conditions of storage, the food will keep in good condition for at least six months. But if, in the laboratory, there is a difference in the quality of the food after six months, then the result will be disappointing when the process is put into commercial practice. As a rule there is more fluctuation in temperature in commercial storage, handling, and transportation than in a laboratory.

Minus 10° C. is an important temperature, because below that point molds and yeast scarcely multiply at all. It is true that some bacteria survive and may multiply very slowly at temperatures below —10° C., but the multiplication is so slow that they do not cause spoilage. If bacteria, yeast, and molds were the sole consideration, it would not be necessary to hold frozen foods below —10° C. Unfortunately, other changes are very active at —10° C., for example, enzyme action in damaged tissues. At this temperature many active enzymes oxidize foods, change their flavor, and destroy vitamins and other nutritive values. Similarly, chemical actions occur rapidly at —10° C. and there is also rapid desiccation at this temperature. Many cold-storage men feel that extremely low temperatures cause severe desiccation. This is a mistake. In general, the lower the refrigeration temperature, the less the rate of desiccation, other factors being the same. If, however, a cold-storage room designed to maintain a temperature of —10° C. is reduced in temperature by putting in the room enough coil to bring the temperature down to —25° C. without increasing the insulation, the humidity of the room is greatly reduced and refrigeration is not as satisfactory as in a properly constructed storage room.

Many whole fruits oxidize very rapidly; they change even more rapidly after they have been cut. They must be frozen in a way that will retard oxidation. Similarly, if vegetables are not treated in some manner to inactivate the enzymes, they become oxidized; the enzymes become so active that they lose their flavor. Further, frozen vegetables which have not been treated prior to freezing soon develop peculiar flavors which are undesirable. Consequently, vegetables must be treated by heating or by blanching so that all the tissues come up to at least 90° C. before freezing; then they must be cooled rapidly.

## IMPORTANCE OF RAPID FREEZING

Fish and meat products which are frozen rapidly—by quick freezing—are better than the products which have been frozen slowly. Research has proved this beyond reasonable doubt. There are various explanations to account for the better quality. Some believe that

it is solely a matter of size of crystal and destruction of tissue by sharp crystals. This is only a partial explanation. Fish fillets and steaks and steaks of lean meat should be frozen rapidly enough so that the colloidal content is maintained pretty much as it was in the fresh state. In other words, it is necessary to freeze rapidly enough to form the crystals uniformly throughout the tissues and so fix the original spatial distribution of the colloid. The size of ice crystal is of some importance but it is more important to freeze fish or meat so rapidly that there is not time for migration of moisture from the tissues. If possible the moisture should be frozen in its original position before there is time for large ice crystals to form and the soluble components of the meat or fish to migrate into the liquid which has not been frozen. It is also of some importance to carry out this rapid freezing at a relatively low temperature so that practically none of the moisture remains in the fish or meat as unfrozen moisture.

Considering fish, it is evident that low temperature is of special importance in slowing up the oxidation of fats. Fish oil (fat) is highly unsaturated and can be used for painting walls of buildings, metals, etc. Fish-oil paints are a little more flexible and not so brittle as linseed-oil paints. Fish oil has a capacity for absorbing oxygen readily; unheated fish contain oxidizing enzymes which hasten this action. The fat-oxidizing enzymes slowly cause the fat or the oil of the fish to combine with oxygen, which results in a rancid flavor. For the first month or two, when the difference in flavor is not so noticeable, it is not considered rancid but only stale. Later, when the oxidized flavor becomes pronounced, it is rancid.

Changes in the proteins are also pronounced, but the lower the temperature the less the change in the proteins. Proteins of frozen fish, when held for long periods at relatively high temperatures, become denatured, lose water, and become tough. Along with that change in the colloids there is a change in the flavor. When quick-frozen fish are thawed immediately after freezing, practically no drip or leakage occurs, but if fish are held at $-18°$ C. for a year there is a very considerable amount of drip or leakage because of the changes in the proteins. The lower the storage temperature, the slower the changes occur; in fish held at $-25°$ C. the change occurs very slowly; even after a year it is difficult to distinguish between freshly caught fish and those that have been frozen and held at that temperature.

How can many of these changes be checked by means other than simple use of low temperature? One means is by glazing. This has been used for many years as a means of preventing oxidation. If there is a film of ice over the fish, the air is shut out and oxidation is reduced to a minimum. Glazing must be repeated at bimonthly and sometimes at monthly intervals. The lower the storage temperature,

the less often it is necessary to glaze. If the fish are held at —40° C., one glazing is all that is necessary. At —18° C. they must be reglazed every other month. Fillets can be protected from the action of air by packing in air-tight packages. If metal containers are used and the fish held under vacuum, oxidation is checked. It is the common practice in United States of America, Canada, and certain European countries to dip lean fish fillets in a relatively concentrated brine for a short period. This treatment reduces leakage or drip to a negligible amount. The brine coagulates the protein on the surface so that when the fish is thawed, the drip or leakage is not lost; however, it can be pressed out.

One innovation in the last two years in the United States has been the treatment of fatty fillets with a very dilute ascorbic acid solution. If a small amount of ascorbic acid (vitamin C) is used in the water in which the fish are glazed, the ice film over the fish absorbs any oxygen which otherwise might pass through the ice and no oxygen can come into direct contact with the fish. This relatively new practice is used for fatty fish so that the flavor is little changed by freezing and storage.

In the case of meat, low temperatures are required to stop chemical actions, enzyme actions, desiccation, and loss of flavor. The meat must be packed in such a way that the oxygen cannot come into direct contact with it. Air-tight and nearly air-tight packages are often used.

## *THE FREEZING OF FRUITS*

Fruits are greatly changed by freezing. Strawberries, which in the fresh state are plump and firm, almost collapse with freezing. If they are frozen in liquid air or with extreme rapidity, the collapse can be partially prevented. If not frozen with great rapidity, they become flabby when thawed, and a large proportion of the fluid in the strawberry drips out. Most fruits have very active oxidative systems; even at —18° C. there is rapid oxidation. Peaches change very slowly to brown and eventually to black because of the oxidation of catechol-tannins. Oxidative changes must be prevented. Fruit flavors are volatile, and it is necessary to pack fruit, and particularly strawberries, in such a way that there is relatively little chance for the loss of aroma. Temperatures of —18° C. or lower should be used for fruit storage.

Only a little air causes oxidation of fruit. One way of retarding oxidation is to pack the fruit in a tin container and seal it under a high vacuum. However, vacuum-packing of frozen fruits is seldom practiced. If strawberries are packed in heavy syrup or mixed with

sugar, the voids between the fruit are filled and most of the air is eliminated; further, the syrup or sugar retards enzyme action. When peaches and strawberries are preserved for desserts, the method most generally used is to slice the fruit, mix it with a heavy syrup or with sugar, and pack it in air-tight containers. The sugar or syrup slows up enzyme action, and prevents oxidation, and the air tight containers prevent the loss of aroma.

In 1938 it was found that ascorbic acid prevents the browning of cut fruit as long as the ascorbic acid itself is not oxidized. Ascorbic acid does not act as a antioxidant, but absorbs the oxygen so that the oxygen from the air does not combine with the catechol-tannins of the fruit. Thus the fruit retains its original color and flavor.

## THE FREEZING OF VEGETABLES

Finally, there are the principles applied in the freezing of vegetables. It has been pointed out that vegetables also have active oxidative enzyme systems. Vegetables frozen in the garden and allowed to thaw are substantially worthless. If, on the other hand, the tissues are heated to 90° C. or higher before freezing, then the vegetables may be frozen and thawed without marked change in flavor. Heating, freezing, and thawing wilts vegetables, changing the colloidal state. For that reason, only those vegetables generally used for cooking are commonly frozen. If radishes are heated, then frozen, and afterwards thawed, a very limp and inedible product results. The same is true of celery which is to be eaten raw.

Good packaging is necessary to keep frozen vegetables in good condition. If they are allowed to dry out they change in texture and lose flavor. Peas, for example, lose flavor if permitted to desiccate, their epidermis becomes a little tough, and they lose their bright green color.

In some cases freezing actually improves the quality of certain vegetables, especially if they are properly blanched or heated before freezing. This may seem strange, for in general a frozen vegetable is never better than the original product. Certain vegetables, such as broccoli, cauliflower, and Brussels sprouts, in the course of blanching lose some of their strong taste, actually improving their flavor.

For an excellent frozen product, vegetables of high quality must be selected and handled with great rapidity so that no deterioration takes place during preparation for freezing. The temperature for vegetables storage must be low, otherwise they lose their bright green color. If the storage temperature is as high as —10° C., in about three months the vegetables begin to lose color and flavor, become definitely inferior, and eventually become inedible.

## STORAGE TEMPERATURES FOR FROZEN FOODS

In general, the lower the storage temperature, the longer any given frozen food can be held without noticeable change of flavor, color, and vitamin content. In most instances the same holds true for texture, although the texture of fruits packed with sugar or in a heavy syrup may be adversely affected at temperatures low enough to freeze the syrup absolutely solid. Some manufacturers of strawberry preserves hold their berries at —8° to —10° C. in the belief that the berries are better suited for use in preserves if the fruit is not held at low temperatures.

All available evidence indicates that the texture of all other foods is retained best at very low temperatures: When stored at —8° to —10° C. most fish become tough and "chewy" in about six months. At —18° C. these changes in texture in fish are not noticeable for 10 to 12 months, and at temperatures of —24° C., changes should not be noticeable in less than a year.

Most of those who have studied the effect of storage temperatures on the retention of vitamins in frozen vegetables and fruits have found that the lower the storage temperature, the more perfectly the vitamins are retained. Of course, some vitamins, such as thiamin,

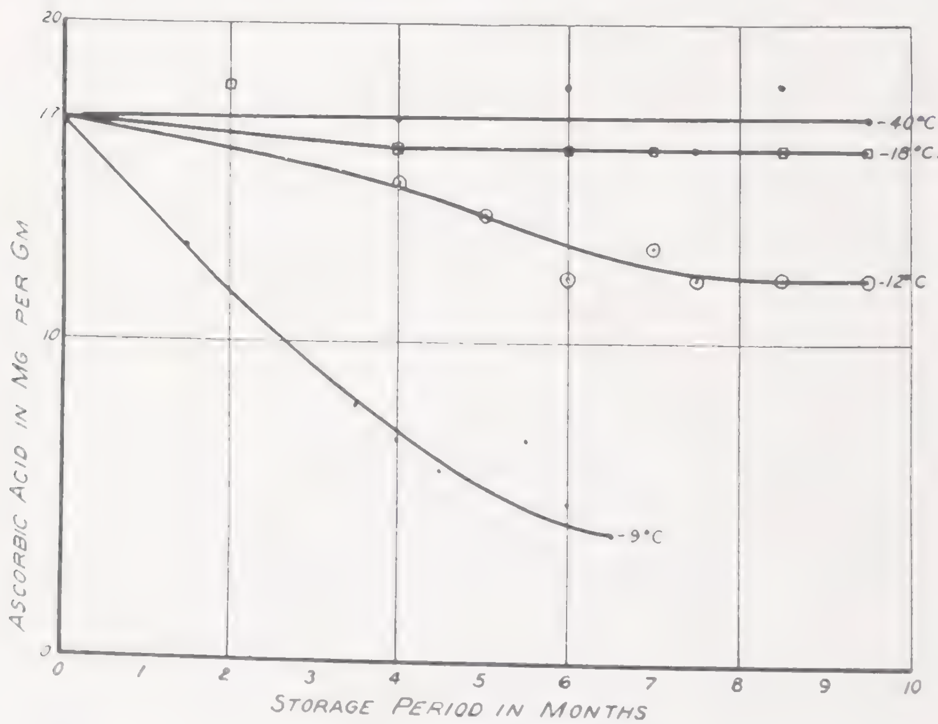


*Figure 1. Loss of vitamin C in frozen peas during storage at various temperatures.*

are not lost regardless of the storage temperature. Vitamin C, on the other hand, is lost at a rather rapid rate if frozen vegetables and fruits are stored at —8° C. or above. At —18° C. the rate of loss is much slower and at —40° C. none is lost in a year (Figure 1).

The rate of vitamin C loss is not the same in all vegetables. Asparagus and some green beans lose vitamin C very rapidly at temperatures above —18° C., whereas the rate of loss from peas and lima beans is relatively slow.

The rate of palatability deterioration and loss of green color from vegetables usually parallels the rate of vitamin C loss. In fact, vitamin C content is one of the best indices of quality for frozen vegetables. If a frozen vegetable has the normal vitamin C content, it is highly probable that the vegetable was harvested at the proper stage of maturity and that it was promptly and carefully prepared for freezing and then frozen and stored under proper conditions. Mishandling of green vegetables at any time is likely to cause severe loss of this vitamin. For example, blanching too long washes out a considerable proportion of the water-soluble vitamin content. On the other hand, inadequate blanching does not inactivate the oxidizing enzymes. During storage, these enzymes greatly accelerate the rate of vitamin C loss.

Some frozen products retain their palatability amazingly well when stored at —18° C. Cooked squash, whole-kernel sweet maize, apple juice, beef, and several other products if properly packaged do not change noticeably for a period of two or three years. On the other hand, a number of other frozen foods are likely to deteriorate markedly in six months at this temperature. These products, which require special care in packaging and low storage temperatures, include among others fatty fish of all kinds (especially salmon), poultry, peaches, apricots, asparagus, maize on the cob, snap beans, lobster, and cooked shrimp.

## PACKAGING

The way a product is packaged has a great influence on the length of time that it will keep in storage at a given temperature. Products to be kept for any considerable length of time should be packaged to prevent desiccation and retard oxidation.

Meats, poultry, and fish can best be packaged by wrapping in a highly moisture-vapor-proof sheeting or by placing them in a package which is nearly impervious to air. Rubber compositions such as Cry-O-Vac and Pliofilm are among the best. Specially coated vegetable parchments and moisture-proof cellophane are also excellent materials for use as wrappers and as liners for cartons.

Metal and glass containers are commonly used for fruit juices and certain other products. Large enamel-lined tin cans are used for much of the cold-packed fruits. Metal and glass containers are not only absolutely moisture-vapor-proof, but are impervious to air. Such containers are necessary for use in packaging easily oxidizable products such as orange juice. The use of air-tight containers greatly increases the storage life of any product at any given temperature.

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# 2. Ice— Production and Use[1]

ARTIFICIAL ICE has been produced for many years as ice blocks, using big tanks with brine, heavy hoists, ice crushers, etc. Today, however, more direct methods make ice in minute form direct from the refrigerating machine. Such machines occupy considerably less space than the block ice plant and, especially for smaller installations, they are much handier.

It is, in fact, rather easy to make artificial opaque ice with a refrigerating machine, a brine tank, and some ice cans. It is only necessary to put fresh water into tapered molds (ice cans), place the molds in cold brine, lower the temperature of the brine below 0° C., keep it at this temperature until the water is frozen, take out the molds and immerse them in lukewarm water to loosen the ice from the molds. This produces blocks of milk-colored ice with a high heat-absorbing power. But the public wants clear ice at low cost.

For many hundreds of years natural ice has been taken from lakes or ponds in winter and stored in insulated ice houses, or in stacks covered with heavy layers of sawdust or sea grass. Such natural ice may be cheap when it can be obtained near the place where it is to be used, but it is not clean, and the possibility of obtaining ice during the winter depends upon the severity and length of the cold periods.

In the central parts of Norway and Sweden, for instance, there is always natural ice in sufficient quantities in winter, but on their western shores, and in other countries with warmer climates, there is no certainty of having sufficient ice to cover the requirements of the following summer. As an example, in the large fishing port of Bergen, Norway, natural ice has to be transported a great distance and has always been rather expensive.

When the first refrigerating machines appeared in the middle of the

[1]Based on a paper presented by Erik Holten.

last century, they were used at once for making artificial ice. Such ice, however, is no more artificial than natural ice: both kinds have the same physical properties and their cooling effect is the same. Artificial ice is only the general term for ice made by a refrigerating machine.

## ICE-MAKING SYSTEMS

In some dairies the evaporator coils are immersed in ordinary water, from which ice is frozen on the coils. In this manner, with a small refrigerating machine, it is possible to accumulate from the ice formed on the coils a considerable amount of cold which, during a short period, may be transferred to a milk cooler.

The evaporator may also consist of one or more small containers with double walls, or ice can be formed by a vertical shell and tube condenser. The refrigerant evaporates in the hollow space between the walls or between the tubes and the shell, freezing the water in the container or in the tubes. The ice is loosened by means of hot refrigerant gas.

In recent times much ice has been made on drums cooled inside by circulating cold brine or evaporating ammonia. Double-wall drums are also used, with ammonia evaporating in the hollow space between the walls. The water to be frozen is sprayed on the drums, or they are immersed or dipped in the water or filled inside with water, while the ice is scraped, ground, hammered, or broken off in thin scales. Ice frozen in this way may be called quick-frozen as against the more slowly frozen block ice.

There are many types of drum machines, the most important of which are the Flak Ice, the Pak Ice, and the Scale Ice systems.

### Flak Ice

Flak Ice is formed on the outside of a hollow drum made of flexible sheet through which brine cooled to about —10° C. is circulated. The drum is immersed in an insulated fresh-water tank. The ice is cracked from the drum by means of inside rollers pressed against the drum. The ice cracks off in pieces about 3 mm. thick. It is removed from the machine in a dry condition and stored in double-walled refrigerated bins.

### Pak Ice

Pak Ice is formed on the inside of a stationary cylindrical drum with a hollow wall. Ammonia evaporates at —16° C. in the cavities of the wall, cools the wall, while fresh water filling the inside of the

drum freezes in a thin sheet. The ice sheet is removed by rotating scrapers, the ice floats on the top of the water and is skimmed off. This ice is not dry, but rather slushy. Pak Ice is used either in its original snow-like form or pressed into small briquettes to be used instead of crushed block ice.

### *Scale Ice*

Scale Ice is ice in sheets about 2 to 3 mm. thick, formed on the outside of a rotating double walled drum. Ammonia evaporates in the hollow space between the walls at a temperature of —18° C. or below, while water is sprayed on the outside of the drum, forming a sheet of ice which is scraped or broken off. Scale Ice is dry and may be used in the same way as crushed block and Flak Ice.

The Pak Ice machine, the Scale Ice machine, to a certain point the Flak Ice machine, and similar drum machines working with direct expansion and without brine as an intermediary, represent a type of ice-making machine that may be predominant in the future. At any rate it will be used for small and medium plants with a daily output from 2 to 20 metric tons of ice for packing fish.

These machines occupy a comparatively small space as they have no big ice generator tank, no expensive ice cans, etc. The ice they produce is smoother and does not damage fine and delicate fish such as herring so much as the crushed block ice with its large and small irregular lumps. Furthermore, these machines can start at full capacity in a few minutes and can work continuously.

### *Ice Blocks Frozen in Cans*

The method of ice-making, however, which has hitherto been most commonly used and which probably will continue to be used for bigger plants is to freeze water in blocks in ice cans. The ice is formed in tapered blocks weighing from a few kilograms up to about 200 kg. and is used in whole blocks or as crushed ice.

When ordinary raw water is put into an ice can immersed in brine of —8° to —10° C., and is not stirred, the water freezes, commencing by the formation in the water of a net of ice needles growing out from the can walls. However, the water contains various salts—most frequently calcium salts—and some dissolved air. If the water is still, these salts and air bubbles deposit evenly on the ice needles throughout the block. If this happens, the finished ice is opaque, and such ice is not popular. Crystal-clear ice is preferred because clear ice is more attractive and seems cleaner, and because it is said that opaque ice melts quicker than clear ice. There are various opinions on this last point, but the latent heat is the same for both.

The most effective way to get clear ice is by removing the salts and

the air by distilling and reboiling the water just before freezing it. Such water produces crystal-clear ice when the brine temperature is held at about −6° C. (Figure 2). However, this procedure is rather expensive. It is cheaper to prevent the salts and the air bubbles from adhering to the ice needles during the freezing process. This is easily done by agitating the water during freezing. The water can be agitated by shaking thin sticks or chains in it, or, better, by blowing air into it, through pipes of small diameter. Air agitation has been commonly used for many years, either by hanging the pipes in the center of the can and using a low-pressure blast or by high-pressure blast from the bottom of the can. In either case there is a thin opaque core in the middle of the block in which all the salts are collected. This core may be reduced by pumping out the water in the core before the block is finished and refilling the hole with fresh water. High-pressure blast makes more attractive ice than low-pressure blast, but the appearance of the ice also depends considerably on the hardness of the water. For this reason the water is often softened before freezing.

Brine temperature is of great importance, the freezing time of an ice block with given dimensions being longer at a high brine temperature than at a low one and the slower an ice block is frozen, the clearer the ice will be. Figures 3, 4, and 5 show ice blocks formed with the aid of shaker sticks and low- and high-pressure blasts.

When using crushed ice for packing fish, it is often considered an advantage to have both clear pieces and snow, and this is best obtained by crushing clear ice blocks with a rather big opaque core.

Ice should be stored for some time at about −6° C. so it is well cooled before delivery.

## USES OF ICE

Ice can be used in blocks, as crushed ice, as scale ice, flak ice, pak ice, etc.

Ice blocks are used for cooling ice chests or refrigerators for families or big establishments to preserve foodstuffs of all kinds. Large quantities of ice in blocks are used for cooling railway cars for transport of perishables such as meat, fish, fruit, and vegetables. But most block ice is used in crushed form.

Crushed ice, scale ice, etc., is mainly used for preserving fish and fish fillets. It cannot be overemphasized that this is the most effective manner of cooling fish when it is not desired to freeze them.

Fish must be cooled as soon as possible after capture and killing, because the bacteria and enzymes in and on the fish are more active at low temperatures than in the meat of warm-blooded animals.


*Figure 2. Crystal ice produced from distilled water.*

*Figure 3. Clear ice with opaque core produced from ordinary raw water using shaker sticks.*

*Figure 4. Clear ice with opaque core produced from ordinary raw water using low pressure blast.*

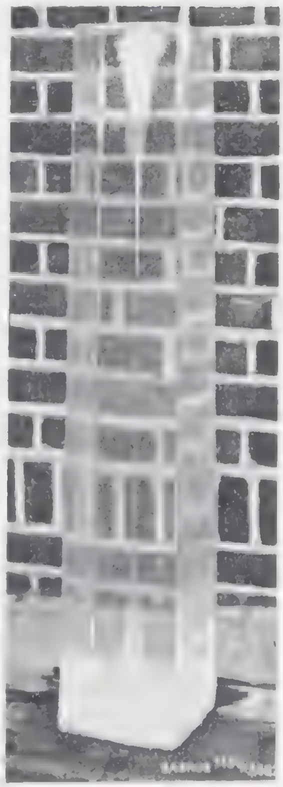

*Figure 5. Clear ice produced from soft raw water, by means of high pressure blast.*

*(Courtesy of Thomas Ths Sabroe & Co.)*

Fresh fish—not frozen—cannot be preserved satisfactorily in a refrigerated chamber without ice, for two reasons: cooling is too slow and the fish skins and natural slime dry out. If fish are packed in ice, this cools them very rapidly and at the same time the ice keeps the skins and slime humid.

An example of the use of ice for cooling fish is the procedure followed at Esbjerg, Denmark, home port of more than 500 fishing vessels. The vessels are mostly of 30 to 70 metric tons, fishing for plaice, cod, haddock, herring, and many other fish in the North Sea and more distant waters. Each boat takes on 8 to 20 metric tons of crushed ice at Esbjerg. At the fishing grounds, the crushed ice is arranged in a layer of about 30 cm. in the first bins to be filled, then layers of fish are alternated with layers of ice in such a way that there is always about 30 cm. of ice between each layer of fish and between the fish and ship's side. In this manner the fish are surrounded by ice, most of which remains until the vessel returns to harbor.

Another important use of crushed ice and scale ice in Denmark is to keep fish fillets cold during their transport from Denmark to countries as far away as Switzerland. The fillets are packed in parchment in 1-kg. packages. Baskets or wooden boxes are lined inside with about 10 cm. of wood shavings. A layer of ice is placed on the wood shavings, and the packages of fillets are placed on this, possibly with some ice between them, and all of the fillets are covered with an ice layer, which is covered with about 10 cm. of wood shavings under the cover.

All of the packing material is precooled and the packing is done in a refrigerated chamber. Fish fillets so treated are in excellent condition upon arrival in Switzerland and are sold there one or two weeks after leaving the packing plant in Denmark.

Crushed ice is used to cool bottled milk in dairies and during transport in insulated trucks; it is used with salt to cool ice cream boxes; it is used in sausage-making and to cool rye-crisp, especially in Sweden.

To keep vegetables fresh during transport and in the retailer's shop, fine crushed ice, flak ice, or scale ice can be spread over them. It does not damage lettuce, spinach, or other delicate vegetables, but keeps them fresh and in excellent condition. Fine ice, like snow, can be blown over boxed vegetables in railway cars so that the entire load is surrounded with ice (Figure 6).

Ice is normally made from pure water taken from the mains or from ponds, and does not contain large numbers of bacteria. Since there are always bacteria in fish, it has been proposed to mix the water to be frozen with antiseptic materials, or to sterilize the water with ozone before freezing, or to mix the crushed ice with dry ice. It has been proposed to add hydrogen peroxide to the water in connection with addition of various salts to lower the pH. Other salts

*Figure 6. One of the best ways of refrigerating vegetables for transport is to cover them with a blast of finely crushed ice*

and a special salt "Entozon," produced by the I. G. Farben works, have also been proposed to sterilize the ice, but none of them is used in Denmark. A difficulty in adding such salts to block ice is that they cannot be evenly distributed, but collect in the center of the block and do not spread evenly throughout the crushed ice. In quick frozen ice, however, the salts are evenly distributed in the ice.

Ice is sold by the block, by weight, or by volume. Block ice is sold in whole blocks for use in railway cars, in halves, or smaller parts for use in ice chests. The customers know the normal weight of a block, and weighing is done only periodically for the sake of control. Block ice is also delivered as crushed ice. The quantity is controlled by weighing on automatic balances before delivery, or by counting the blocks before crushing, in which case it is practical to have block weights of 100 or 125 kg., or eight to ten whole blocks to a metric ton. Crushed ice, scale ice, etc., may also be delivered in boxes or sacks containing a certain quantity, the weight of which has been fixed once for all. Flak ice and the like may be distributed in cartons and sold from ice cream boxes just as ice cream is sold. This was done in the United States many years ago, but this product was called recently in England "the new form of ice." This method may be developed further by grading the ice in different sizes to be sold in cartons for various purposes.

Using pure ice made from ordinary water, only temperatures down to —0° C. may be obtained. When the ice is mixed with sodium chloride, temperatures down to —21° C. may be obtained, and with other salts even lower. Ice frozen from water containing sodium chloride has a melting point down to —21° C. Such ice, called minus ice or eutectic ice, may be used for cooling trucks transporting frozen products. Minus ice produced by quick-freezing methods has a considerable advantage over block ice, considering that the salt has even

distribution only in ice frozen almost instantaneously in thin scales. In blocks, the ice from the center of the block contains much more salt than the rest.

## DRY ICE

Dry ice is made from carbon dioxide ($CO_2$), which has a solidifying point of —78.9° C. One kilogram of water ice requires 80 calories at 0° C. to melt it, but 1 kg. of dry ice can absorb 152 calories at the same temperature. Dry ice is carbon dioxide in a solid condition. It is made from pure carbon dioxide gas compressed and expanded, and thereby cooled to its solidifying temperature.

The carbon dioxide is obtained in several ways. It can be obtained directly from the earth through $CO_2$ wells. It can be produced by burning coke or other fuels. It can come from breweries, where the fermenting wort gives off carbon dioxide. In most cases raw carbon dioxide must be cleaned, for dry ice must be clean and free of any strange odor.

Dry ice must be kept in open containers at atmospheric pressure. A small amount of the carbon dioxide will then vaporize and keep the remainder cooled to about —78.9° C.

Dry ice should not come in contact with fresh foodstuffs being cooled; it freezes them. The foods being cooled must be more or less insulated from the dry ice.

When used for cooling a railway car, a truck, or a container, the dry ice may be placed on shelves at the top or in slightly insulated bunkers, or it may be placed in a bunker well-insulated from the body of the truck or car. A secondary refrigerant or brine cooled by the dry ice in the bunker circulates through coils in the body of the truck, thus refrigerating it.

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# 3. Household Refrigerators, Home Freezers, and Locker Plants[1]

## HOUSEHOLD REFRIGERATORS

A HOUSEHOLD REFRIGERATOR must conserve many kinds of fresh and prepared foods and possibly also frozen foods. Satisfactory results cannot be expected when foods requiring different temperatures and different degrees of humidity are put into a refrigerator without considering their sensitivity to these variations.

A comparison of the original refrigerators with the latest models reveals that, apart from the better workmanship and design, technical improvements in the later models result in more efficient conservation of foodstuffs requiring varying conditions of coldness and humidity.

As a rule, the machinery of the first refrigerators consisted of an evaporator with float valve and a small compressor guided by a low-pressure control, with $SO_2$ as refrigerant. Generally it is considered an advantage that the machinery of a refrigerator plant is amply dimensioned, but for a household refrigerator this is a disadvantage; the plant must be exactly adjusted to the load, and this applies to the compressor as well as the cooling surface.

Moreover, there is a special condition in connection with household refrigerators—the demand for freezing ice cubes. This must take place within a reasonably short time, two to three hours, without reducing the temperature of the refrigerator too much. In the beginning this problem caused trouble. In order to keep the compressor working for a suitable time in order to freeze cubes, the evaporator temperature was reduced to —15° to —16° C., and the result was often too low a temperature in the refrigerator.

[1]Based on a paper presented by S. Mansted.

The heat leakage is generally calculated at about 55 kgcal/hr for a 143-liter (5-cubic foot) refrigerator and about 80 kgcal/hr for a 300-liter (10-cubic foot) refrigerator when there is a difference of 20° C., between the temperature in the refrigerator and that of the surrounding air. At first—and it is still true of some of the existing household refrigerators—the capacity of the compressor was often 200 to 250 kgcal/hr at an evaporating temperature of —15° C., while it ought not to be more than about 100 kgcal/hr. Too large a compressor always gives unsatisfactory performance; either the evaporator temperature will be very low, which means considerable formation of frost on the evaporator and a considerable drying out of the foods, or, if this disadvantage is avoided by increasing the evaporator surface, there is too short a working period of the compressor, causing difficulties in freezing the cubes in the trays.

Furthermore, users have complained that prepared foods from the refrigerator lose a good deal of their flavor and acquire "another taste," which is due to desiccation and rapid air circulation in the refrigerator. It may be difficult in the small cooling space of a household refrigerator to obtain satisfactory conditions for conservation of all kinds of foods at highly varying conditions of temperature and humidity.

In the main the following factors are decisive for satisfactory conservation in small as well as large cooling areas: (1) *Cleaning of the*

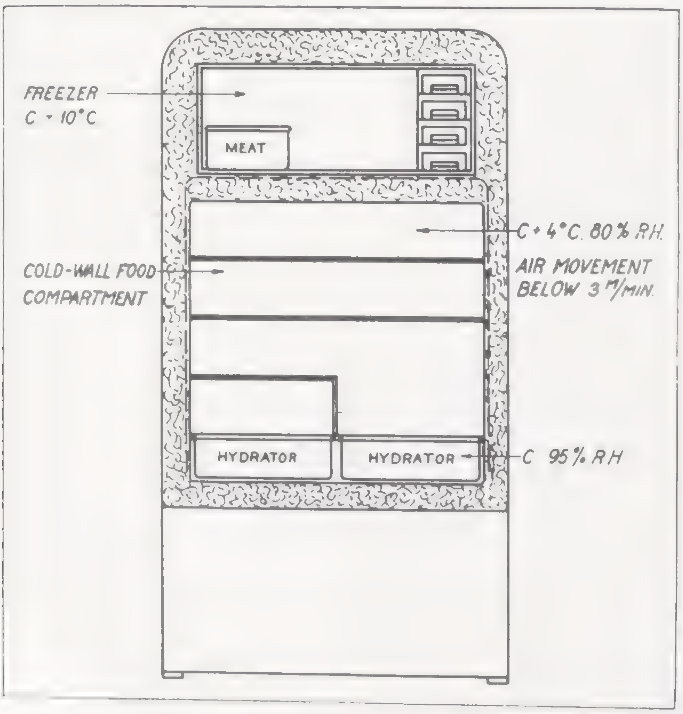


*Figure 7. Interior of 1948 model refrigerator.*

*(Courtesy of Atlas Maskinfabrik, Copenhagen.)*

*refrigerator and its equipment.* This should be done as a matter of course, but it is of great importance that the refrigerator and its equipment be made so that cleaning is easy. (2) *The quality of the foods conserved.* It is still necessary to point out that cooling cannot improve the foods, but can only maintain the quality existing at the time of placing them in the refrigerator. (3) *Temperature of the air in the cooling space, degree of humidity, and circulation.* Most refrigerators are provided with a temperature regulator so that the temperature desired can always be maintained. On the other hand it is usually impossible to interfere with the degree of humidity and the air circulation, although these factors have a great influence on the quality and loss in weight of the foods. In the household refrigerators previously built, and in some still being constructed, the humidity can fall to about 55 percent at +5° C. and at the same time the air circulation is lively. This is a result of the low evaporator temperature caused by too large a compressor. Under these conditions, uncovered foods can lose 20 to 25 percent of their weight within seven days, and the appearance and taste are greatly changed. This disadvantage is remedied by wrapping the foods or placing them in closed containers or hydrators, which are mainly used for vegetables. Wrapping or covering various foods prevents, to an essential degree, the transmission of smell and taste from one kind of food to another.

In several of the newest types of household refrigerators these decisive factors have been taken into account, and the cooling has been arranged and the refrigerator equipped in the following ways (Figure 7): A freezer with a reasonably large cooling surface is built as a box with a door in front and separated from the other part of the refrigerator, and is furnished with ice trays and space for conservation of frozen foods; Closed drawers are provided for raw meat or fish at temperatures of about 0° C., placed directly under the cooling surface; The remaining part of the box of the refrigerator is cooled either by a minimum air circulation along part of the surface of the evaporator or by a secondary evaporator coil placed along the outside of the refrigerator box to make the air rather stagnant and moist; Hydrators are provided for vegetables, etc., and a suitable refrigerating unit is exactly adjusted to the refrigerator.

In a refrigerator of this type it is possible to maintain the temperature in the evaporator-freezer at about —10° C., and in the refrigerator box at +4° to +50° C., with a relative humidity of about 80 percent. Uncovered foods can be placed in the refrigerator box without any significant loss (about 6 to 7 percent of the weight in seven days).

The frozen foods in the freezing compartment must generally be wrapped in moisture-proof cellophane or something similar. The vegetable drawers must not close hermetically, but must have a fair

sized opening toward the box of the refrigerator. Otherwise the foods may mold. This refrigerator will, of course, be somewhat more expensive than the ordinary types with the cooling surface directly in the refrigerator box, but the difference in price must be compared with the advantage of being able to put foods in the refrigerator without wrapping or protecting them in some other way against drying or transmission of taste.

However, the modern standard refrigerator with one evaporator can give absolutely satisfactory results if foods likely to dry out are protected by wrapping or covering.

Power consumption of a 143-liter (5 cubic-foot) refrigerator is about 1 to 1.25 kilowatts per day.

## *HOME-FREEZERS*

Fresh foods—prepared as well as unprepared—should not be stored in a household refrigerator for more than a short time; raw meat should be kept only a few days. Frozen foods in the evaporator, when the temperature is maintained at —14° to —15° C., may be stored for two to three months.

With the well-known home-freezers where the temperature is maintained at about —18° C., a valuable supplementary use of the refrigerator has been found, especially for users who can grow their own vegetables and fruits and do their home-killing. Figure 8 shows a refrigerator with a cooling cabinet and freezer. However, in Denmark, home-killed meat was frozen for several years before the first home-freezers of the present design appeared about 1940. For many years it has been a general custom for the manager of a rural dairy to arrange a freezing box of about 300 liters in one of the brine tanks of the dairy, and although the temperature is only about —10° C., a whole or a half pig can be stored there for two or three months.

*Figure 8. Combination household refrigerator and home freezer with 200-liter space for cooling and 140-liter freezing compartment.*

It was not until the war years that interest in home-

freezers in Denmark increased, especially among those in rural areas. The volume of the freezers produced in this country usually varies from 200 to a little over 300 liters. The biggest type can hold a pig and a small calf, suitably quartered.

Home-freezers of many types and sizes are rapidly coming into use in the United States of America. In the cities and larger towns the most popular freezers are those having a capacity of about 100 liters. In the small towns and suburban areas large numbers of 200 to 300 liter freezers are in use. On the larger farms home-freezers with a capacity of 1,000 liters or even more are common. Some of these freezers are provided with special freezing compartments; others are not. In the United States locker plants are used principally for the freezing and storage of meat and poultry, but home-freezers are more likely to contain considerable quantities of fruits, vegetables, and cooked foods. Proper packaging or wrapping of meats, poultry, and fish is considered essential for the proper storage of these products in both home-freezers and lockers. Further, all fruits and vegetables are packaged in air- and liquid-tight containers.

A farmer who cannot afford a large home-freezer often buys a small one to keep in his kitchen or pantry as an auxiliary to the frozen-food locker which he rents in a plant some distance away.

## LOCKER PLANTS

The development of locker plants in Denmark will serve as an example of recent progress in this important phase of food preservation.

Home-killing has always been common in Denmark, mainly on the farms, but in many provincial towns and villages also the housewives killed the "Christmas pig." The part of the meat that could not be used during normal storing, without cooling or as a prepared product, was cured or smoked, to be used mainly in the summertime, as ham and bacon (but, of course, with reduced food value and appearance). Vegetables and fruits are preserved to a considerable extent. The first locker plant in Denmark (Figure 9) was built in 1943 at Mons Co-operative Dairy, where it was installed with 180 boxes in existing rooms. The meat and poultry were not wrapped or frozen when put in. The boxes were made of round galvanized bars with a door and padlock, partly because cheap construction was wanted, and partly because at that time it was impossible to get sheets for closed boxes. At the beginning it was rather difficult to rent the boxes; skepticism of this new storing method was strong among the dairy shareholders and customers had to be found as far away as Stege, a town about ten kilometers from the dairy.

It was not long before considerable interest developed and the next year the plant was increased by 100 boxes, making a total of 280 boxes. The following year it was reserved for the dairy shareholders only. It was now clear that this storing method was much better than the brine tub; killing could take place in the summer; poultry ready in November could be killed and stored until Christmas or longer; food was saved.

By the end of 1945 and the beginning of 1946, interest in locker plants reached a new

*Figure 9. Interior of first locker plant in Denmark. This open type of construction permits severe desiccation of unwrapped frozen produce. (Courtesy of Atlas Maskinfabrik, Copenhagen)*

high and a series of plants was erected. Experience had been gained and United States publications furnished valuable information on the performance of locker plants.

The plants in Denmark were made with freezer plates for freezing at about $-25°$ C.

*Figure 10. Interior of up-to-date Danish locker plant. Note overhead plate evaporators and modern steel lockers.*

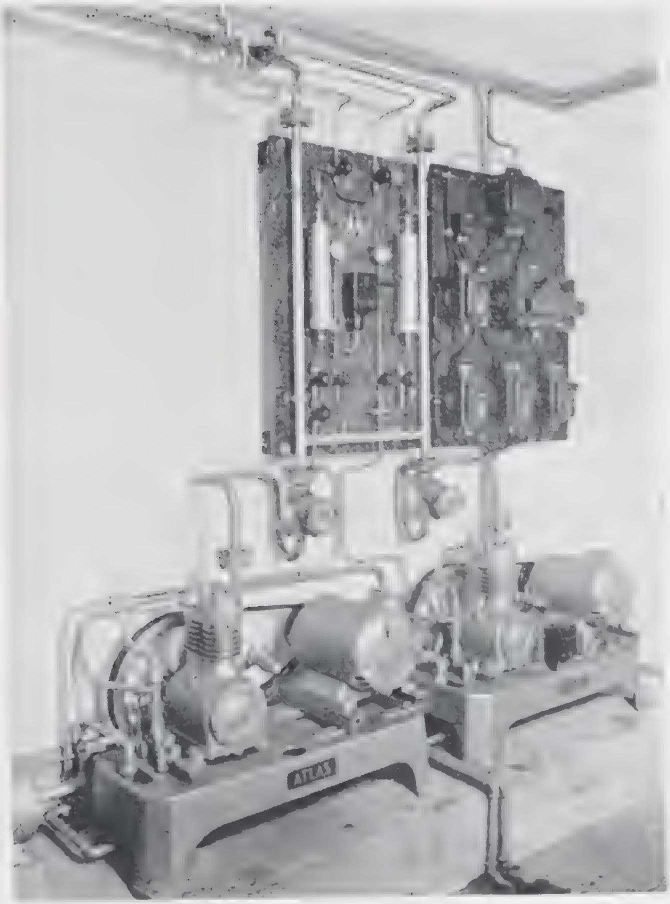


*Figure 11. Locker plant engine-room with two automatic Freon refrigerating units. Either unit is sufficient to refrigerate the plant temporarily if one is disabled.*

and some plants were made with enclosed steel boxes (Figure 10). These boxes were 510 mm. wide, 770 mm. deep, 400 mm. high and had a capacity of 155 liters. Unfortunately, the great lack of sheets, still prevalent in Denmark, quickly limited the use of steel boxes, and a great number of plants had to be made with slatted wooden boxes. These are cheaper and are made to standard dimensions so that they can be replaced by steel boxes when steel sheets can be obtained.

As a rule the engine plant is made with two or more automatic Freon compressors (Figure 11) so that half of the engine plant can always provide the cold consumption for a prolonged working time in case of emergency. By this method it is also possible to obtain a proper division according to the evaporating temperature. Instrument boards with stop valves, filters, gauges, etc., are conveniently placed to provide the best possible view.

The freezing rooms are cooled by finned coils with built-in heating elements for defrosting, or with overhead cold-plate evaporators

*Figure 12. Refrigerated plates in the freezing cabinet of a locker plant. The shelves are maintained at approximately —25° C. All food is packaged and then frozen before it is placed in the lockers. (Courtesy of Atlas Maskinfabrik, Copenhagen.)*

placed directly under the ceiling. The overhead cold-plate evaporators are used to a great extent and have many advantages. Defrosting is easily effected by brushing, as opposed to finned coils which must be warmed by electricity or hot Freon vapors. By this warming, necessary heat passes into the room, reducing the economy. In addition, forced air circulation over the finned coils causes much desiccation when compared with the "gravity cooling" of the overhead cold plate evaporators shown in Figure 10. The freezing shelves in a locker plant are shown in Figure 12. The temperature in the box room is kept at about —18° C. The anteroom, in which the foods remain only for a short time, is cooled by a coil with a fan and kept at a temperature of about +2° C.

Various plants having from 30 to 600 boxes have been installed in Denmark. Most plants have an average of about 200 boxes. Locker plants are generally established on a co-operative basis, and in many cases the idea begins in a co-operative dairy or society. From there the matter is further developed, and as a rule results in an independent co-operative with its own rules. It is set up for a period of not less than 25 years, and, as an economic basis, it is assumed that the engine plant will be written off in 15 years, the buildings, boxes, and other fittings in 25 years. Electric current, water consumption, and a sum for operation and maintenance of the plant must also be taken into account. For a plant of 250 lockers the rent is about 60 kroner per locker per year. Many private plants have also been constructed for renting lockers, and the owners of such plants often offer a special service to customers, collecting and delivering the goods on fixed days of the week (for instance, Hjorring Freezing House has 600 lockers and collects and delivers foods in insulated trucks).

Home-killing is a common practice in Denmark, and there are no slaughterhouses or preparing rooms, in connection with the locker-plants such as are often seen in the United States.

Up to now principally meat, pork, bacon, poultry, and game have been placed in Danish locker-plant boxes, but there is an increasing interest in the freezing of fruits and vegetables. Many of the locker-plants will be too small when the boxes are required to hold these products, because as a rule the ordinary Danish farm household preserves large quantities of home-grown products.

The packing of the goods is not yet as it should be, mainly because it has not been possible to procure the packing materials required, such as moisture-proof cellophane, cartons of standard make, and stockinettes.

Because of the lack of foreign exchange, the authorities do not permit the import or manufacture of these materials. The Danish Refrigeration Institute and the State Household Council have carried on considerable propaganda for preservation in freezing rooms, partly by sending out pamphlets and partly by publishing practical instructions, for the many home economics advisers throughout the country. Unfortunately the general building stoppage imposed in August 1947 limited rapid development, but the general hope for the future is that a large number of plants will be installed, and that each county and town in the country may get its own plant. There is also great interest in the villages in the provinces, which primarily are farming areas.

The small and average sized farms and households take a keen interest in using the lockers in a locker-plant, but most large farms will purchase their own home freezers often combined with a household refrigerator. In 1948 about 265 plants were working in Denmark, with a total of about 50,000 boxes, but many plants were projected and awaited building permits.

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# 4. Construction of Cold Storage Plants

## PRACTICAL CONSIDERATIONS [1]

THE SITE for a cold-storage plant should generally be in a center of distribution. Supplemental plants may be necessary in centers of production, but they are more difficult to maintain in full economic use, are generally smaller in size, and of a specialized character.

The best transport facilities should be provided—railroad sidings, access to good roads, parking space for vehicles, and, where water-borne traffic has to be dealt with, wharf accommodations with cranes for loading and unloading.

### Building

The design of the storage plant as a whole should provide the best facilities for handling the goods—a factor that is often overlooked. Some engineers are more concerned with economy in refrigeration power than in manpower. When these two factors are in conflict it is usually preferable to give preference to the manpower factor, even at the expense of the power of refrigeration.

Fixed conveyers and similar mechanical devices can seldom be profitably used in a cold storage plant; the goods must be handled manually from the vehicle in which they arrive or into the vehicle in which they are dispatched. It is simplest, then, to use a truck for internal transport of goods to and from their stowage space.

Manual stowage limits the height of stow to a little more than 2 meters. Therefore, considering the economy of labor it is not

[1] Based on a paper presented by A. G. Clausen.

usually economical to construct storage rooms having a greater height than 2.5 or 3 meters.

Structural considerations of the floor loads for which a building can be economically designed impose similar limits on the permissible stowage heights within the upper floors in buildings of more than one floor.

Lifting trucks can be used for stowage to much greater heights; they have great advantages where objects of regular size and shape are dealt with, but there are difficulties in using them for the great variety of shapes and sizes of the commodities that have to be handled by the general cold-storage plants. Like all specialized machines they are very good for special purposes, but they are not suitable for all the goods that have to go into cold storage.

The loading platform should be with the floor of the railway cars or road vehicles serving the store; this fixes the level of the ground floor, furnishes the datum line at which to start, and provides an air space below the cold store—the simplest method of avoiding the troubles that may arise from freezing the ground underneath.

When deep foundations are required it may be possible to excavate to a sufficient extent to construct basement rooms. These are useful as general cool storage but should not be used for cold storage at temperatures below the freezing point. Besides, the cost of excavated space is almost invariably greater than the cost of a similar space constructed above ground. A basement has an average lower temperature, but the median temperature is practically the same.

The number of floors to be provided must be determined by a number of considerations:

(1) In large cities, where sites have a high value and are restricted, it may be necessary to construct a building of several floors.

(2) Somewhat more than half the power used for refrigeration in the average installation is required to extract the heat passing through the external surfaces. For economy of operation the ratio of surface to capacity should be small.

(3) A single-story building can generally be made to provide the greatest capacity for the least building cost; its equipment is simplest and cheapest, for no lifts or hoists are required. Operation is simplified if the floor joints are not too large.

(4) A single-story building gives a large ratio of surface to capacity and is bad in that respect; it therefore requires more power for refrigeration than one which more nearly approaches a cube.

(5) With multifloor buildings the space occupied by elevators, stairs, and halls becomes excessive, thereby reducing the proportion of the total space that can be made available for cold rooms.

(6) When there must be more than one floor, elevators or hoists become necessary. Since the expenditure incurred for this purpose can

be made to serve more than one floor, two floors are not economical and can be ruled out.

The insulation of external surfaces represents a large proportion of the total cost of insulation. In a single story plant having a large surface ratio, the power required to operate it and the cost of insulation are increased approximately in proportion to the ratio.

When the site imposes no restrictions it is probable that the lowest total cost, the greatest convenience, and the earliest completion are obtained by constructing the smaller plants as single-floor buildings, but that buildings of three or four floors should be constructed for the storages of 500 to 2,500 metric tons capacity.

Single-story cold storages can follow the simplest factory construction. They can be formed within any normal form of multifloor building if existing buildings have to be used. But, in new construction, the choice lies between reinforced concrete and structural steel construction.

Buildings should be of the curtain-wall type, with all floor loadings carried on internal columns to permit the external insulation to form a complete envelope, broken only by the ties that must be provided between the outside wall and the internal structure.

These ties must permit the relative movement caused by variations in temperature to which the parts are subject, and very careful consideration must be given to this aspect of the construction of all large cold-storage buildings. Expansion joints in buildings are objectionable as a possible source of weakness in weather-tightness of the structure, but they are less objectionable on that account than the structural cracks that may result from their omission.

Deep beams should be avoided on the construction of floors. With reinforced concrete a "mushroom" construction should be adopted to provide flat floor slabs. With structural steelwork the main beams to support the floors should be arranged in one direction only and the crossties between them fixed within the thickness of the floor slab. The beams can then be used as the spaces or sites of air ducts or, if the rooms are piped, the piping can be arranged between them so that there is no loss of storage space.

Structural steel construction has the advantage that it provides better facilities for the support of pipes, air ducts, or hanging rails for meat; it allows these to be improvised to a much greater extent than is possible with reinforced concrete and permits work to proceed while the engineers are working out their final details. Structural steel also provides greater scope for small alterations in design that so often have to be made during the progress of work, or for alterations that may be desirable.

Floors should be finished in granolithic or other hard-wearing surfaces treated for a dustless finish. The floor surfaces immediately in

side and outside the cold store doors should be laid with steel-faced or similar tiles to withstand the wear of trucks.

Goods in cold storage should be supported by dunnage on the floors to provide an air space of about 7.5 cm. With care in design a proportion of these can be permanently formed on the concrete floor, but they should not obstruct the access of trucks to all parts of the room and they should be laid in the direction that assists air circulation.

### Subdivision of Cold Storages

In England the function of most cold-storage plants is the storage only of goods that have been chilled or frozen in some separate establishment and that enter the storage at a low temperature. That is to say, the cold-storage plants are used mainly for the storage of food which has been frozen in Australia, New Zealand, South America, United States of America, and in other distant parts of the world and which arrives in a frozen state. These goods can be taken directly into the storage rooms, the slight increase in temperature resulting from transport being insufficient to affect goods already stored.

If, however, the incoming goods are in a warm condition they must be cooled and, if necessary, frozen in separate spaces before they are transferred to cold storage. On the Continent the majority of cold stores are used for both purposes and must have accommodations for freezing and storage. The rooms used for freezing can be used for storage, but should not be used for both purposes at once.

Cold stores are used for a wide range of products that may require different temperatures and may in some cases have to be isolated so that their odor does not affect other goods.

Stowage should be done in such a way as to provide access to any consignment of goods at any time; this may be difficult in very large spaces. A capacity of 200 to 250 metric tons is about the maximum that should be provided in any single space. Very large rooms often make handling more difficult. A general cold-storage plant should permit the fullest possible use of its space for any class of storage with the minimum of subdivision. This adds greatly to the cost.

In a purely functional establishment such as a meat plant it is possible to design for a definite program. That cannot be done for general cold storage; it must be prepared to deal with the unforeseen. Successful design, however, must be based on a reasonable estimate of the quantities and kinds of the products to be stored, their rate of arrival and their condition at entry.

### Insulation

Many materials can be used for insulation, but loose fillings should only be employed when no satisfactory form of slab is available. Slabs of compressed cork remain standard.

The test rate of heat transmission through cork slabs should be increased by about 30 percent to allow for the effect of joints, imperfections in workmanship, the tie bars that must extend through the insulation, and the infiltration of air which cannot possibly be stopped, in order to arrive at the refrigerating power that must be provided for heat losses through the insulation.

The thickness of insulation must be governed by the relation between its first cost and the cost of power required to operate the refrigerating machinery. The usual practice in England is to provide for the walls about 1 centimeter of cork for each 2° to 2.5° C. difference between the temperature to be maintained inside and the mean summer temperature outside. A greater thickness should be used for flat roofs exposed to the direct rays of the sun and a smaller thickness for the floor. Cork slabs to make up the total thickness should always be applied in two thicknesses laid to break the joint in both directions. Where greater capacity is required it may be necessary to use three layers.

Cork slabs can be fixed to walls and floors with cement or bitumen, and the same materials are used for fixing the second layer to the first, generally with the addition of wooden skewers driven at an angle.

Internal partition walls and floors must also be insulated when they separate spaces that may have to be maintained at different temperatures. It is advisable to use two layers and the thickness applied is generally greater than that given by the rule for outside insulation. This provides for the contingency that these walls may in effect become an outer surface if the adjoining space is out of use.

An ideal construction for insulation would have an outer skin that is completely impervious to air and water vapor and an inner lining that does permit the passage of air and water vapor. The inner lining should at the same time be hard and smooth so it can easily be kept clean and resist the damage from rough usage. This is practically impossible to attain.

Asphalt or bitumen, properly applied, makes a more impervious outer skin on the external walls and ceiling, but it may soften on surfaces exposed to the sun and there is then a risk of the insulation falling inside. In such situations it is advisable to use cement, but the choice between cement and bitumen should be decided by the class of labor and the supervision available. The efficiency of insulation depends to a very large extent on the skill and care used in its application.

Insulation must be laid on a ground floor and a working floor laid over it, but the intermediate floors are best insulated on the underside only, the cork slabs being set up in the forms and the concrete

poured directly on it. The objection is made that this method soaks the cork with water, but it dries before the cold store can be put into use, so there is no loss of efficiency. This method is simple, effective, and secure.

Columns projecting through floor insulation must be insulated on their sides to a height of 1.25 to 1.5 meters. This insulation should be strongly protected at the corners to prevent damage from trucks.

Internal structural walls, when required, can be built directly on cork insulation, but if their height exceeds about 3 meters it is advisable to use cork slabs which have been more heavily compressed. There is no need to leave any breaks in the cork envelope.

Flat concrete roofs can be insulated on the underside in the same manner as intermediate floors, or the cork can be laid on top of the structural roof slab, graded, and waterproofed. The latter method makes it unnecessary to insulate the upper portions of columns and reduces structural stresses caused by temperature differences, but it calls for considerably greater care in design and workmanship at the junction of the roof and the walls. Cork laid on the top of a roof must be exposed to the weather until it is covered, but heavy rain or even snow does not appear to affect its efficiency if it has reasonable time to dry out before the storage plant is cooled.

Internal surfaces of cork insulation can be finished with cement mortar applied in two coats and finished with a wooden float. The cement unfortunately cracks at regular intervals, but its appearance can generally be saved by scoring. Cracking can be avoided by the use of softer plasters, but these generally disintegrate under cold storage conditions, and bitumen finishes are too easily damaged.

Fixed dunnage battens must be provided for all walls to provide space for air to circulate between the walls and the goods stored. They are generally made of timber in sections about 50 by 50 cm., spaced about 30 cm. apart.

Cold-storage doors should provide a clear opening of about 1.25 meters width; they must be hung to give a clear opening and should swing easily. The fastener must operate from both sides; it should be capable of taking a padlock for locking. The lower halves of door and frame should be protected by galvanized steel sheets to prevent damage from trucks.

## *Temperatures and Humidity*

In England the temperature maintained in cold storages varies with different conditions, but can be considered as falling into one of three general groups: (1) About 0° C. or slightly above for provisions that are maintained in a chilled state and would be damaged by freezing—mainly fruits, eggs, meat, etc. (2) About −10° C. for frozen beef and butter being preserved for long periods. This is the general

storage temperature in Great Britain. (3) About —20° C. for quick-frozen provisions of all kinds.

In the first group, precise temperatures and their maintenance without appreciable variation are most important. In the second and third groups the precise temperature is not of great importance, but it is necessary that it be constant, with a minimum of variation.

The humidity to be maintained in a room kept at 0° C. or higher should be as high as possible to avoid loss of weight by evaporation or surface drying, but not high enough to encourage the growth of molds during storage. This condition is generally realized with a humidity of between 80 and 85 percent, which is fortunately provided by the usual arrangements adopted for refrigeration, and it is seldom necessary to take measures either to increase or to decrease the humidity that is naturally attained.

### Refrigerating Machinery

Ammonia-compression-refrigerating machinery is recommended for commercial stores of any large size. There should be a stand-by for each working unit or sufficient spare parts to ensure continuity of operation. It has been usual in the past to provide two compressors, one working and one stand-by. Much greater economy of operation can be obtained by installing three or even four compressors of a smaller size, of which only one need serve as a stand-by. This permits the refrigerating power available to be more closely adjusted to the duty.

The working compressor unit should have sufficient power to maintain the required temperatures throughout cold storage space when it is run for 16 hours per day during very hot weather and when all the rooms remain closed. This provides greater economy than can be obtained by devices for reducing compressor capacity either by clearance pockets or by-passes.

Condensers can be of the shell and tube type when ample supplies of condensing water are available. If dirty river water is used, the vertical type is preferable, as the tubes can be cleaned while the plant is in operation. When water is scarce, shell and tube condensers can be used in conjunction with cooling towers, or the condensers may be either the older atmospheric type in favorable situations or the more modern forced-draft evaporative type.

Cold-storage rooms can be cooled by air circulation only, by piping, or by a combination of these two methods. In any case the refrigerant can be used directly or it can be used to cool brine which is in turn circulated through the cooling appliances as a secondary refrigerant.

Air circulation only should be used for rooms cooled to 0° C. and higher temperatures. It should be used in all cases for the rapid

cooling or freezing of warm products and it is suitable for the lower temperatures. It may be described, indeed, as a universal application, though piping alone is preferred for rooms that are definitely used for frozen storage temperatures and particularly for those in the lowest temperature range. Air circulation from one air cooler must not be made to serve rooms in which products may be stored that would taint others.

There is very little difference in the total cost between a storage that is cooled by a single air circulating system and one which is cooled entirely by means of piping, but if there are large numbers of rooms that must be maintained as independent spaces, the balance of cost falls largely in favor of the pipe system. A combination of both systems also, of course, increases the first cost.

Ammonia can be used as a direct refrigerant in all cases, but where there are large numbers of circuits the use of brine as a second refrigerant simplifies the engineer's work of control.

In all cases the flooded system is best. Pump circulation of the liquid should be provided for extended circuits. In direct systems, the economy gained is indicated by the fact that when the older "direct-expansion" systems are converted to conform with modern practice there is a power saving of at least 25 percent and possibly as high as 30 percent.

## Accessory Parts

One or more platform-type weighing machines must be provided for the receipt and dispatch of goods, with a platform large enough to carry the trucks used. There should be a small covered office or enclosure adjoining for the checker.

There must be ample provision of easily maneuverable trucks suitable for the products handled. Each truck should have its weight given on a metal label. Truck weight must be checked at regular intervals; it tends to increase.

Except in the smaller stores, elevators should have a cage large enough to take two trucks and the operator. It is usually best for one man to transport a truck from the platform to its final destination in the cold-storage rooms, so that elevator control should be push-buttons in the cage. In large storage-plants, however, it is generally better to have one gang on the platform, an elevator operator, and another gang serving the cold-storage rooms. A general rule which seems to work is to provide one elevator per 1,000 metric tons total storage capacity.

The lighting in cold-storage rooms should enable the operators to distinguish marks on goods in any portion of the rooms without portable lamps. Excessive lighting should be avoided, but the heat

the remaining coil area, whereby a better drying effect is obtained for the same amount of refrigeration.

The use of forced air circulation in coolers should be reserved for special purposes. High storage temperature in coolers enables the air to take up large absolute quantities of moisture, and heavy weight losses may occur very quickly if forced air circulation is used.

For *receiving rooms*, where warm goods have to be cooled down, or in *freezing chambers* for the freezing of goods, there is no danger in the use of forced air circulation. Weight losses are unavoidable during the cooling or freezing of goods unless the goods are protected by a moisture-proof wrapping like Cry-O-Vac or similar material. The mechanism of the evaporation in this case, however, is quite different from the evaporation during the state of equilibrium in the storage room. The source of heat for the evaporation is no longer the surrounding air but the warm goods themselves. Theoretical calculations and practical tests show that 20 to 40 percent of the heat removed from unprotected meat when it is cooled or frozen is a result of evaporation from the meat. High air velocity does not always cause higher evaporation. A dry skin of a hygroscopic nature is rapidly formed in forced air circulation, and evaporation is retarded. The faster the temperature is lowered the better, and forced air circulation is generally recommended for freezing. Also, reversing the air direction in many cases reduces freezing time and is preferrd to higher air velocities, which take larger fan motors with extra heat loads.

## Location of Coils

When goods are stored in a freezer without forced air circulation, their temperature is lower than the air temperature. The air is therefore cooled at the surface of the goods, which would cause an air movement downwards. At the same time, however, the goods give off water vapor, and, as water vapor has a lower specific weight than the dry air, this causes an air movement upwards. A further study of this process leads to the conclusion that the resulting driving power always is directed downwards, and the air around moist goods in equilibrium in a freezer store therefore moves downwards. If, however, meat or other foodstuffs with a high water content are brought into the freezer storeroom without being completely cooled to the storage-room temperature, or in some cases not completely frozen, then evidently the air movement around the goods is upward because the air around the goods raises both its temperature and its humidity, and these two factors together create an upward movement of the air. If the coils are placed on the sides of the goods, there is always a natural and favorable air movement as long as the goods have a higher temperature than the air, for there is a downward air move-

ment at the refrigerating coils and a rather strong upward air movement around the goods. Therefore, there is very little risk in placing all the coils at the walls. In critical cases, where the food is incompletely frozen or cooled before it is put into the freezer store, coils on the ceiling provide an unfavorable air circulation compared with coils at the walls.

The coils of a low temperature room should, for obvious reasons, be made as prime surface coils. It is necessary to keep the refrigeration coils free from surplus snow by scraping and brushing the pipes at intervals in order to obtain good heat transmission and the cheapest possible refrigeration. Fin coils should, therefore, not be used in freezer stores. Prime surface coils can be placed either on the walls or on the ceiling. Ceiling coils are very often used, but they should be avoided because of the difficulty of proper scraping and defrosting. Scraping, brushing, and defrosting can be done with the coils on the ceiling, but this involves extra labor cost. Radiation from the ceiling does not justify coils on the ceiling. Small or medium-size cold-storage plants usually have available walls for a sufficient coil area. This is always the case when the room area is 200 m² or less. If the room area is larger, then the layout should provide aisles for transport and all the coiling should be located on the walls and over the aisles so that scraping and defrosting can be done without moving the stacks of goods.

## *Optimum Amount of Coil*

The refrigerated coil area is of course dependent upon the location of the freezer and the surroundings of every room. In the United States a widely used ratio is 1 linear foot of a 2-inch tube per 5 to 6 cubic feet of refrigerated volume, which corresponds to 0.3 to 0.4 $m^2/m^3$ of storage volume. It is better, however, to calculate the coil area for each individual room than to follow any rule of thumb. It is recommended that calculation of the refrigerated coil area be based upon the maximum load, assuming a heat transmission coefficient for prime surface coils of 9 kgcal hr $m^2$ 0° C., and calculating the area for a temperature difference between air and the coil of 4° to 6° C. This coil area is economical and provides a humidity which many times, according to experience, exceeds 90 percent.

It should be remembered that the driving power in cold-storage rooms using prime surface coils is rather small and no hindrance of any kind should be placed underneath the coils (for instance, no drip pans). In cooler rooms fin-type coils can be favorably located on the ceiling, where they can be provided with drip pans to catch water and ice during defrosting.

### *Freezers*

The cooling system in quick-freezing chambers should be of the air-blast type.

Defrosting is usually done by means of hot gas from the compressor, and ice and water are collected in small troughs underneath the coil nest. If there are several freezing tunnels of this type it is practical to arrange them in a row and on the back side to provide a defrosting corridor from which all the defrosting troughs can be emptied. By arranging such a corridor, moisture can be prevented from infiltrating into other corridors and the worst part of the refrigerating plant with regard to condensation and frosting can be isolated within a limited area. Other defrosting systems use water, brine, or electricity.

In a modern freezer storage plant it is recommended that a special receiving department be provided for freezing warm goods before storage. Such a department requires a floor area of only about 8 per cent of the total storage area if the freezing is done in narrow air-blast rooms with efficient two-step compressors. Each freezing chamber should have a floor area of about 3 (maximum) by 9 meters, including coils, which can be placed at the end of the room. A refrigerating effect of 15,000 to 20,000 kgcal/hr at $-40°$ C. should be provided for each chamber, capable of freezing up to five tons of food a day. The necessary fan capacity is only 20,000 $m^3$/hr if automatic reversing of air direction is arranged. The air should be blown across the coil nest and conducted along the ceiling to the door end; it should then pass over the goods, evenly distributed within the room, and enter the coiling from underneath. When the fans are reversed, the air leaves the coil nest at the floor, enters the coiling above, passes the goods, enters the ceiling duct at the door end of the room, and is brought back to the coiling.

In a receiving department, which may consist of six to ten air-blast chambers, meat and bacon may sometimes be only partially frozen with freezing completed during storage. Freezing of goods in storage rooms should otherwise be avoided. So-called sharp-freeze rooms, which can be utilized both for freezing and storage, do not offer a radical or economical solution of receiving problems. Freezing and storing take different types of compressors and equipment. These functions, and the rooms for them, should be kept apart.

### *Cooling Systems*

The simplest cooling system is the *direct expansion* system, in which the refrigerant (e.g., liquid ammonia) evaporates in the piping, of the cold storage rooms. Another system is the *indirect*, in which brine is cooled by the refrigerant and circulated through pipes to

various parts of the building. The brine circulating system is preferred in public cold-storage houses of the United States for use in rooms maintained at temperatures above freezing. The reasons: No claims can be upheld by storers of perishable goods that the goods had been damaged by absorbing refrigerant odors escaping from defective piping. The regulation of proper brine flow to maintain the required temperature is claimed to be less difficult than the regulation of the refrigerant in the direct system. It is claimed that more uniform temperatures can be maintained by the brine system. This concept is changing. It is possible today to make a direct expansion system with pipes so tight that leakage very seldom occurs.

Temperature regulation in a direct expansion plant can be made fully automatic by placing thermostats in every room. The coiling is cheaper in a direct expansion system and only the suction pipelines need insulation; the pressure pipe lines can be left bare if expansion valves are placed at each storage room.

There are, however, other points of view: A direct expansion system contains much more refrigerant than a brine-pipe system. In a small plant of 10,000 $m^3$ refrigerated volume, the amount of ammonia used as a refrigerant can exceed 10 metric tons, and this creates a war risk. Some authorities say that the plant should have bomb-proof tanks into which the refrigerant can be pumped. This is sometimes impractical. Sectionalizing the plant by closing valves so that the ammonia content is split up in a great number of coils and pipe lines is more practical. The remaining refrigerant in receivers can quickly be pumped into a bomb-proof storage tank.

In a direct expansion plant it is recommended, at least for bigger plants, that a flooded system with ammonia pumps be used. For plants with a capacity under 2,000 metric tons, pumps are not necessary for economy. Suction lines should be carefully calculated from the standpoint of *pressure drop*. Even those suction lines remote from the machine room should not have a pressure drop exceeding an equivalent temperature difference of 1° C.

## Refrigeration Requirements and Insulation

One of the most important calculations to be made when planning a cold-storage plant has to do with the capacity of the refrigerating machinery and the refrigerating effect to be distributed to each individual room. The first item in such a calculation is the heat intake through the insulated walls, floors, and ceilings. The next item is heat to be removed from the goods, which includes the cooling to freezing temperature, the latent heat of freezing, and the subcooling of the goods after freezing to the temperature of the freezer storerooms. Warm or cool goods should never be put into freezing stores without having passed through the freezing chambers or tunnels.

However, it must always be assumed that frozen goods will arrive in freezer storerooms incompletely frozen or at least with a temperature above that of the room. A sufficient margin of refrigerating effect must be added to take care of this extra load. In freezing chambers the main load is the latent heat of freezing, the insulation losses here being only a small part of the needed refrigerating effect. But the removal of heat is expensive at low temperatures and freezing tunnels should be well insulated.

To this main load (heat intake through insulation and heat removed from goods) is added the load of warm and moist air coming into the rooms by door openings. As a minimum, the total air volume in the room is changed once a day; in freezing rooms it is changed as many as five times a day. The condensation of moisture in the fresh air entering the room requires little refrigeration and can be neglected. Finally, there is a small extra load for lighting and people working in the building.

There is little use in going into details about *capacity calculations.* For European conditions the insulation of walls, floors, and ceiling should be given a thickness which corresponds to a k-value of about:

| | |
|---|---|
| $k = 0.3–0.4$ | for coolers |
| $k = 0.25$ | for freezers |
| $k = 0.2$ | for quick-freeze rooms and sharp freezers |

Much could be said about the effect of sun radiation, but it is sufficient to say here that an extra 10 to 20 percent should be added for the heat intake through flat roofs and walls facing south. The temperature difference should be calculated, using the highest mean temperature of a day in the neighborhood of the building; in Sweden, for instance, this is usually $+25°$ C.

This paper does not consider the economic thickness of insulation, which is complicated by more problems than are generally assumed, or the well-known formulas for calculating thickness of insulation. A more useful purpose is served by taking up the properties of insulating materials.

## Insulating Materials and their Properties

There are three important factors in the consideration of insulating materials: The k-factor or the $\lambda$-value, resistance to moisture and water vapor, and adaptability to cheap building construction methods.

Resistance to moisture does include durability in the presence of moisture and the ability of the material to maintain its insulating value in the presence of water vapor or condensed moisture. If water is absorbed by porous or fibrous materials and perhaps frozen in the material, the conductivity increases considerably. The curve in Figure 13 indicates the influence of water on the conductivity of cellular or

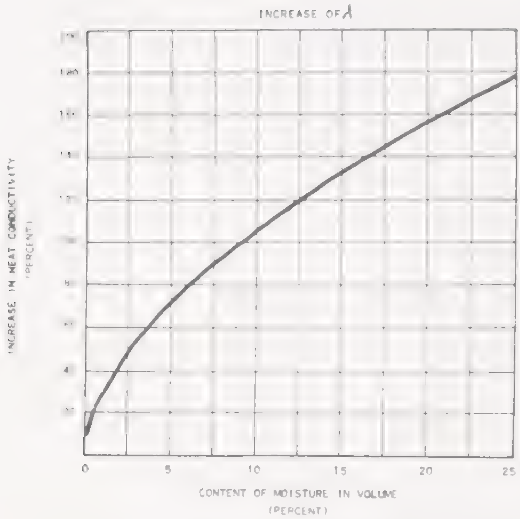


*Figure 13. Influence of moisture content on heat conductivity of a porous insulating material.*

porous insulating materials. Many widely used insulating materials can absorb up to 20 to 25 volume-percent of water. This curve makes clear that the λ-value for insulating materials in a bone-dry condition the figures usually published have only academic value if moisture gets into the material.

*Cork* is a widely used insulating material. Experience has shown that a very efficient cold-storage insulation can be made with cork, but because of its hygroscopicity and moisture absorption the material must be installed with the greatest care. It should always be sealed with first-class bitumen.

Tests have shown that ordinay expanded cork can absorb up to 20 volume-percent of water with an increase of the λ-value of over 300 percent. Expanded cork has, however, a natural ability to repel water, due to a capillary distribution of absorbed water back to the warm side. The practical limit for absorption of water in cork can be fixed at about 12 volume-percent, corresponding to about 200 percent increase of the λ-value.

During the last ten years several insulating materials have appeared on the market which are made of *glass* or material like *glasswool, rockwool,* and *stonefelt.* These materials at first had a structure capable of absorbing larger quantities of water—up to 20 volume-percent. By making the glass fibers very fine, as in Fiberglas, it has been possible to increase the natural drainage of this material so that the maximum content of water is about 4 to 5 volume-percent or lower. These materials have one quality in common—they are noninflammable. Certain grades, however, are impregnated with bitumen, which slows up water absorption but makes the material inflammable.

Many efforts have been made to create a cellular structure absolutely impervious to water vapor. Styrofoam is a plastic material of cellular structure, made from polystyrene or polystyrole. Polystyrene has great resistance to water and water vapor, but it is not completely impervious. Experience has shown that water slowly gets into the material and cannot be removed. It also has a tendency to shrink; it should be used only when completely sealed in bitumen.

A quite different material is expanded glass or Foamglas, which is completely impervious, but has a higher $\lambda$ value than insulating materials in this field in general. Foamglas is made in comparatively small blocks, and the joints are its weak points. The material has been widely used in the United States, especially for floors and military refrigerating plants. However, the building costs are high because thick walls are necessary.

There are a few other cellular materials, principally expanded rubber compounds, which are comparatively tight to water vapor. These materials are expensive and they have not been known long enough to assess their durability and shrinkage.

To overcome water-absorption difficulties in cellular and fibrous materials there are also in the market multi-layer insulations built of various materials. Alfol is made from aluminum foils, but is little used in cold storage plants. Isoflex is made from plastic film materials, for instance, cellulose acetate or polyvinyl chloride film, which are unaffected by moisture. Inspection after many years in use at a temperature of —20° C. has shown that it is possible to keep this insulation completely dry. Other air-layer insulations are built from impregnated paper, but they are badly affected by moisture if it is allowed to be soaked. When using such materials, cooled air should be circulated in the insulation in order to prevent soaking by condensation.

## Vapor Barriers

Regardless of the type of insulating material used, it is important to prevent water vapor from penetrating the outer walls. Because of the ever-present difference in water vapor partial pressure in the air outside and inside the cold-storage building, there is always a migration of water vapor into the building. The difference in partial pressure in water vapor usually has the value of 0.1 atmosphere. Concrete is comparatively easily penetrated by water vapor. A concrete wall 3 cm. thick, at 0.1 atmospheric pressure difference, has a penetration of 0.5 grams of water per hour per square meter. Every gram of water that goes through the outer wall condenses in the insulation or freezes, lowering the insulation's efficiency. Even if insulation is not affected by absorption of moisture, some water vapor enters the building anyway, and each gram of water absorbs 0.6 to 0.7 kgcal., since the latent heat for water vapor is about 600 calories and the latent heat for freezing about 80 calories. So, even from this point of view it is wise to have a vapor barrier as close to the warm side as possible.

When the water vapor gets into the insulating material it enters existing capillary tubes due to the hygroscopicity of the material.

When it arrives at the layer of the insulation where the temperature is reaching the dew point, condensation takes place. Farther in, a temperature is reached where freezing occurs. Condensed water, and even ice, has a water vapor pressure which usually is higher than the partial pressure of water inside the store room, so it would be possible for the condensed water to migrate through the wall into the storeroom and for the moisture to condense or freeze on the refrigerated coils. Water migration is complicated in many ways by the hygroscopicity of the wall material, which in one way prevents the migration by depression of water vapor in capillaries, but on the other hand may help to bring the water back to the warm side again.

The entrance of water vapor is never completely stopped. The best that can be done is to make the outer skin as tight as possible and the inner wall easily penetrated by moisture so that the water migration can go on which helps to keep the insulating material dry.

The insulation material, theoretically, should either be completely impervious (Foamglas) to the penetration of water or offer as small resistance to water vapor as possible. That is, the material should have no capillaries collecting and holding moisture.

Bitumen is usually used as a vapor barrier. A thin asphalt coating reduces the penetration of water vapor at 0.01 atmospheric pressure difference to less than 0.05 g/hr/m$^2$. It is therefore strongly recommended that the outer walls be given a coating of warm asphalt on the inside, and it is important that the asphalt be applied with the greatest care. Small cracks and holes should be eliminated, for even the smallest hole will permit considerable vapor penetration. It is also important to use the right type of asphalt. The United States of America refrigerating industry recommends a melting point between 90° and 95° C. and certain requirements regarding the content of carbon and sulphur, penetration, and ductability at low temperatures. A construction which has the outer shell as tight as possible, with a comparatively loose inner wall, is called in the refrigerating industry a semihermetic construction. Such a construction is very desirable.

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# 5. Refrigerating Machinery

## *COMPRESSORS FOR REFRIGERATION*[1]

THE COMPRESSOR in a refrigerating circuit is the beating "heart" by means of which the circulating refrigerant is driven through the two other parts of the system. The compressor is therefore a most important and essential part of the refrigerating plant, and the proper working of the plant depends on the efficiency of the compressor and its ability to handle the largest volume of gas with the smallest consumption of power.

The older, slow-speed, horizontal and vertical compressors which were in general use fifty years or more ago, and which are still doing excellent service, have long since been superseded by modern multicylinder vertical types, and the speed is no longer 60 to 100 revolutions per minute but has been gradually increased from 500 to 1,000 revolutions or even more. At the same time, modern methods of manufacturing, and better and more suitable materials now at hand, have enabled the designers to build compressors which, with regard to reliability and efficiency, are just as good as the old types.

Electric power and (where no electricity is available) the Diesel engine, which have superseded the steam-engine, have made the old belt-driven compressors obsolete. Most manufacturers of refrigerating machinery now only make medium- and high-speed compressors, generally vertical machines with two, three, four, or more cylinders. A two-cylinder vertical ammonia compressor of modern design is shown in Figure 14.

Since the advent of the new refrigerants Freon 12 and Freon 22, various other types of compressors have been developed with cylinders placed vertically, or in the form of a V or W, or even radially, as in the Chrysler Airtemp compressor.

[1]Based on a paper presented by O. Kramhøft.

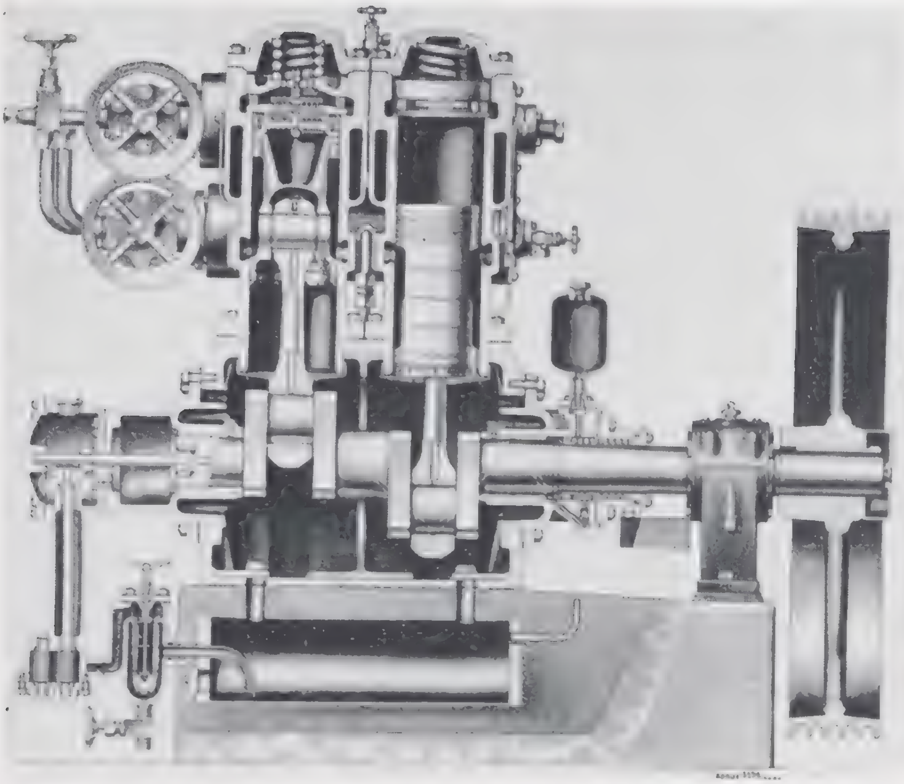


*Figure 14. Two-cylinder vertical ammonia compressor of modern design (Courtesy of Thomas Ths. Sabroe & Co.)*

## Ammonia Compressors

Ammonia compressors are nearly all of the enclosed type, having a horizontal crankshaft with two, three, or four turns from which the pistons receive their reciprocating motion by means of connecting rods.

The compressors are single-acting, mostly with suction valves in the pistons. These pistons are long, having a single or a double intake for the suction gas. The lower parts of the pistons act as crossheads, taking up the side thrust from the connecting rods. Such compressors thus work on the uniflow principle and only the upper part of the cylinders, where the compression takes place, needs to be cooled. Cooling may be effected either by a water jacket or by webs cast integral with the cylinder, whereby the compression heat is absorbed by the surrounding air and by radiation. In some designs the spokes of the flywheel are shaped as vanes in order to blow fresh, cool air over the cylinders. Sometimes the cylinder covers are also cooled.

The delivery valves are placed in a spring-loaded cover which rests against a gas-tight seat on top of the cylinder—a so-called safety head—

which allows the cover to lift when liquid ammonia or excessive oil is drawn into the cylinder. This arrangement safeguards the machines against excessive stresses caused by liquid knocking.

The delivery and suction headers or manifolds are placed on the back side of the machines and are furnished with main-delivery and suction-stop valves together with safety valves and scale-traps to prevent scales and other impurities from entering the cylinders.

The machines are also fitted with cross-connections between suction and delivery sides, and in some cases with an arrangement for capacity reduction, either by means of one or more stop-valves, which, when open, provide passage from the compression space of the cylinder to the suction side, so that compression takes place only when the piston, on its upward motion, covers the opening.

Another principle of capacity regulation is by means of special pockets which serve to increase the clearance space. The actual suction stroke of the piston is thus reduced, because the re-expansion of the compressed gas down to the suction pressure takes place over a greater part of the piston stroke than if the clearance space were normal.

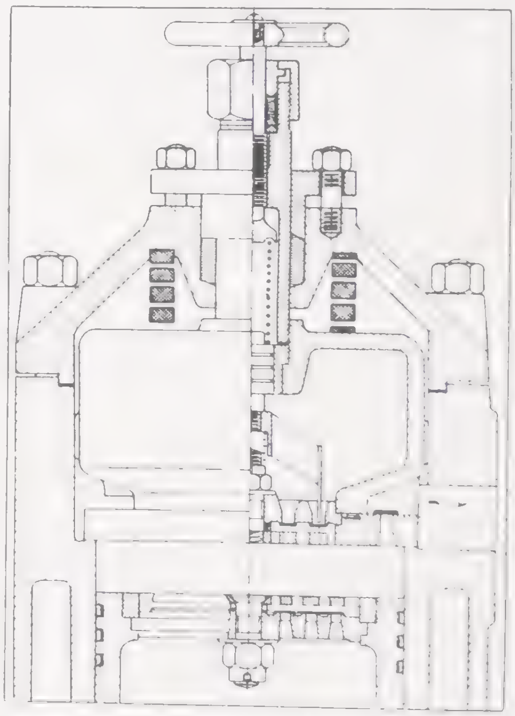


*Figure 15. Hoerbiger capacity regulator. This device permits stepless regulation of compressor capacity. (Courtesy of Thomas Ths. Sabroe & Co.)*

An ingenious device has been invented and designed by Hoerbiger, an Austrian firm (Figure 15), which permits stepless governing of the capacity. It is actuated by means of variations in the suction pressure. This arrangement is very useful, for instance in the refrigerating plant of a dairy where a large-capacity compressor can cool the maximum amount of milk for a few hours and work at a reduced capacity for the remainder of the working time and a normal machine would be too large for the other duties required. As soon as the maximum load is over, there is a sudden little drop in the suction pressure which actuates the capacity regulator so that the refrigerating capacity and the power consumption of the compressor are reduced automatically to the capacity required.

A similar arrangement has been introduced by other designers of multicylinder compressors: one or more cylinders are put out of action by lifting the suction valves one after the other by means of suction devices. This arrangement requires the suction valves to be placed in a special valve plate (which also contains the delivery valve) and not in the pistons. By this design of compressors, short pistons similar to flat top automobile pistons can be used, providing machines are lower in height than the type described above. The enclosed-type ammonia compressor is now furnished by most makers with forced feed lubrication. Splash oiling is used only on small cheap units.

The oil-circulating pumps are in many cases rotary gear-wheel or eccentric pumps driven from the crankshaft and having their axis in line with the crankshaft. The steadily increasing demand for lower temperatures, where the pressure in the crankshaft housing gets down to the suction pressure, makes it necessary to place the lubricating pump at a lower level, submerged in the oil, so that the oil pump has no suction lift.

For plants working with suction temperatures below —30° C., two- or three-stage compressors should be used, and the three- or four-cylinder ammonia machines of the type here described can be employed for this purpose by using two or three cylinders as a low-pressure and one as a high-pressure cylinder.

In a cold-storage plant with several storage rooms and a number of sharp-freezers and quick-freezers, three or more of these compressor units should be used. All units are cross-connected and can be used for single-stage or two-stage operation so that —10°, —20°, and down to —50° C. evaporator temperatures can be obtained at the same time. Furthermore, since all units are identical, all parts are interchangeable and the stock of spare parts can be reduced to a minimum.

In the United States of America so-called "booster compressors" are frequently used in combination with ordinary single-stage compressors to obtain the necessary low temperatures. While it must be admitted that such low-pressure compressors are lighter than the usual compressor, it may be more practical to have units of uniform size, with the same type of electric motors, even if the machinery may cost and weigh a little more.

The stuffing boxes for rotating shafts of the modern ammonia compressors are semimetallic packings which are easily attended to by engineers in charge and give satisfactory tightness when properly oiled. The only objection to this type of packing is the wear on the shaft, but this can be overcome either by having renewable sleeves of suitable material or by chromium-plating the shaft.

Several manufacturers, however, have adopted the rotary shaft seal

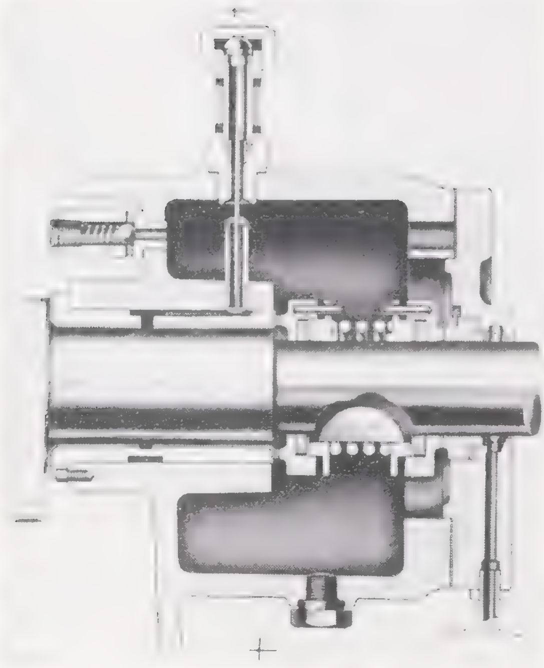


*Figure 16. Rotary oil-seal for enclosed-type compressors. (Courtesy of Thomas Ths. Sabroe & Co.)*

for large-size compressors. This seal has been developed for the numerous types of small compressors for domestic and commercial purposes (Figure 16). Such rotary seals require little or no attention when properly designed and made of suitable materials.

Some compressors have elastic rings of synthetic oil-resisting rubber which are kept tight against the shaft by a compression spring, causing the seal-member to rotate. The compression spring at the same time forces the sealing-member against the fixed seal-member. Other manufacturers prefer seals without rubber rings, because rubber is likely to expand when exposed to oil and ammonia gas, causing the seal to stick to the shaft and preventing the spring from moving the seal-ring, which is necessary to take up unavoidable wear at the sealing faces.

Seals without rubber rings may be flexible bellows of silver, stainless steel, or other material, which is not attacked by ammonia, or flat flexible disks of steel. These disks may be single plates which, near the shaft, carry the seal and, at a certain diameter, about midway between the shaft and the packing of the cover, rest against a sharp edge in the cover. The pressure of the ammonia causes a slight deformation of the disk so that the seals are pressed against each other.

All rotary seals require accurate machining and skilled mechanics to install them in order to achieve perfect tightness.

## Valves

The compressor valves, which formerly were of the poppet-valve type with conical seats, are now mostly replaced by plate-valves.

Although the old-type valves were tighter than the plate-valves and not severely affected by impurities, sand corns, scales, or the like, the weight of a spring-loaded poppet valve does not allow a higher

speed than 300 to 400 r.p.m., even with large diameter and small lift.

The plate valves are of many types. Some makers use Hoerbiger valves (Figure 17), which have two or more concentric rings joined together by webs, the valves being held against the valve seat by springs. The lift is limited by a retainer plate. The plate valves are made of special Swedish steel plate, hardened and ground for the best possible tightness. They are, however, liable to warping and leakage. A better type of plate valve has independent rings not joined together. Each ring has either one large spring or several small ones. Such ring-plate valves have given excellent service, as have the flapper-valves used by one of the leading American manufacturers.

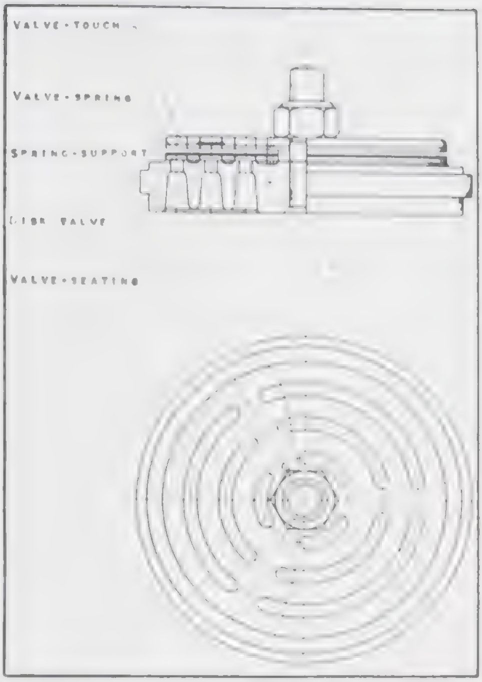



*Figure 17. Hoerbiger plate valve.*

## Freon Compressors

Freon compressors are designed very much along the lines of the ammonia compressors so that a great part of what has already been mentioned applies also to them. Owing to the moderate pressures at which Freon compressors work, in comparison with ammonia machines, the ratio between cylinder diameter and piston stroke can be larger than with ammonia. Generally, ammonia machines have $\frac{\text{Diameter}}{\text{Stroke}} = 1$, while Freon compressors have $\frac{\text{Diameter}}{\text{Stroke}} = 1.28$ to $1.50$. This provides the necessary pace for the larger valves required for Freon. The gas velocities recommended for Freon are 10 to 15 m/sec. in suction valves and 15 to 17 in the delivery valves. The corresponding figures for ammonia are 30 to 50 m/sec. and 35 to 55 m/sec., respectively. As to power consumption, the Freon machine takes about 5 to 6 percent more power than the ammonia machine.

Freon is preferred in several cases because it is regarded as non-toxic, so that it can be used where ammonia machines cannot—for instance in airconditioning and for ships' use (Figure 18). In fact, Freon machines are being used on an increasing scale for marine purposes where the carbon dioxide machines were formerly dominant.

There seems little doubt Freon 12 or Freon 22 will supersede the carbon dioxide machine for marine purposes in the course of a few years.

The greatest difficulty in producing Freon machines is the manufacture of suitable castings. Cast iron for compressor crank cases and cylinders must be absolutely nonporous, to avoid leakage of the gas. Several methods have been tried to fill the pores in the castings. For instance, liquid bakelite has been forced into the pores under pressure and baked at a suitable temperature, but the fumes given off by the process are poisonous and the method does not seem satisfactory. The most rational way is to build the machines of welded steel plates and to have cylinder liners and pistons of cast iron, though this may be more expensive. The all-welded shock-proof Freon compressor is most suitable for marine purposes. All manifolds are usually made of steel tubes and all stop-valve spindles fitted with tight hoods to prevent the escape of Freon gas.

Special oil-resisting packings must be used all over, and, wherever rubber is necessary, a synthetic oil of Freon-proof quality must be used. With regard to lubricating oil, most refrigerating machinery oils can be used, but, since Freon mixes with oil, a higher viscosity is recommended than that required for ammonia compressors. A suitable oil for Freon should have at least 5 degrees Engler at 50° C. whereas 3 to 4 degrees are regarded as satisfactory for ammonia.

## Lubricating Oils

Owing to steadily increasing demands for lower evaporating temperatures required for quick-freezing purposes, the makers of refrigerating machines have sometimes specified oils with freezing points as low as —40° to —50° C. Such oils, however, have correspondingly low viscosities and the result was a large number of scored cylinders and undue wear on moving parts and bearings. Heavier oils are now being used, with the result that the compressors are properly lubricated. All risk of oil freezing in the regulating valves or low-pressure float valves is eliminated by effective oil separators and oil chillers before the regulating valves. Another way is to design the compressors so that the crankshaft and other moving parts are kept outside and separate from the compressor cylinders. This permits a heavier type of lubricating oil to be used in the crankcase. As this oil will not get mixed with the refrigerant, there is no risk of the oil foaming, which often results in most of the oil being pumped over into the pipe system.

A special refrigerator oil with low freezing point can then be used for the compressor cylinders, which in this type of machine are either single- or double-acting with piston rods and one stuffing box for each cylinder. This may be regarded as a disadvantage in com-

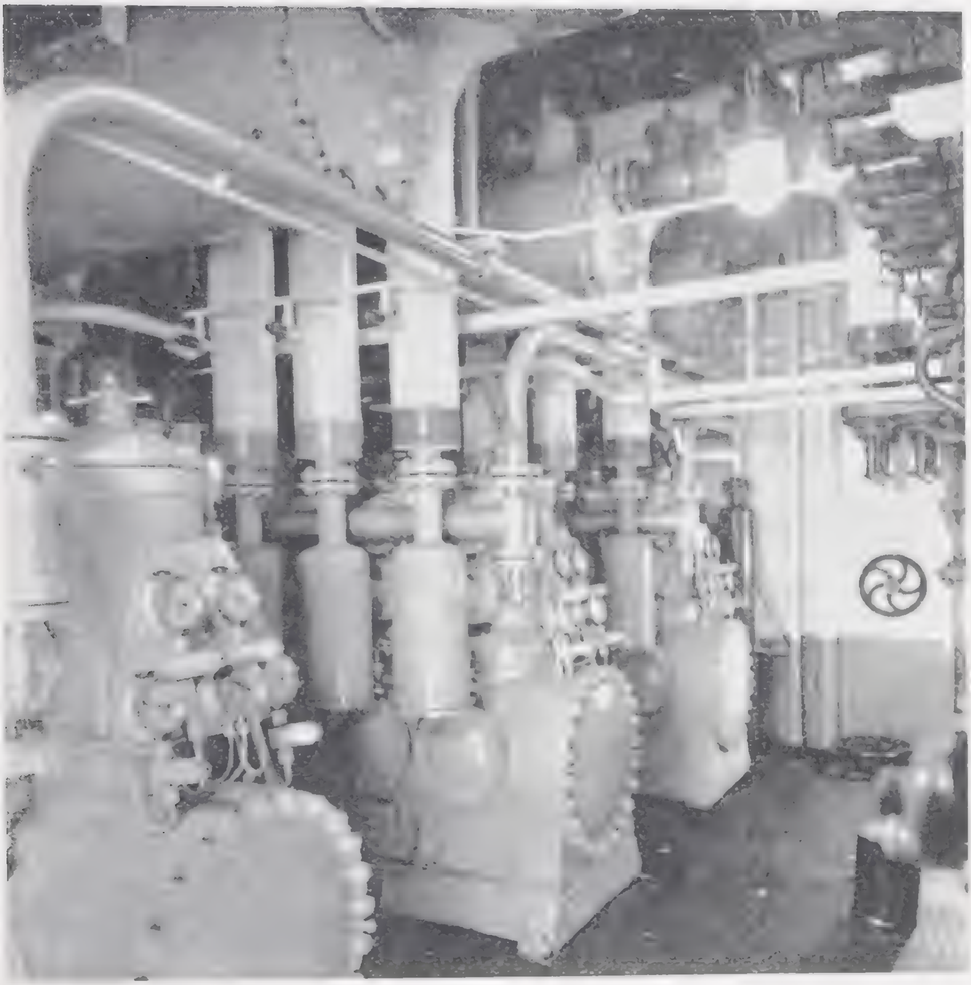


*Figure 18. Marine-type Freon compressors.*

parison with the enclosed type of compressors, where there is but one rotary-sealed stuffing box. However, by special arrangements and proper design and workmanship, stuffing boxes for reciprocating rods can be kept tight, both against pressure and vacuum, and need no special attention.

## Special Specifications

Although compressors for refrigerating machines resemble air compressors in several respects, the manufacturer of compressors for refrigeration must consider several important conditions which do not exist in atmospheric air compressors.

Among these conditions can be mentioned that the materials must be capable of withstanding the action of the refrigerants used. No

part of ammonia compressors can be made of nonferrous metals containing copper, whereas in Freon compressors copper, bronze, and brass can be used without any risk. For both refrigerants the bearings are lined with best quality white metal.

The designer must bear in mind that the compressors must work continuously without attention and all moving parts must have ample bearing surfaces to avoid any risk of overheating. He must take care of perfect tightness to prevent leakage of the refrigerant, a precaution which is not so essential with air compressors.

All parts must be so dimensioned that they can withstand the maximum pressures to which the machines may be exposed when working under the most severe tropical conditions. All parts which contain the refrigerant must, during manufacture, undergo proper testing for strength by hydraulic pressure and by air pressure tests while submerged in warm water as a safeguard against porosities.

The test pressures prescribed by the British Lloyd's Company for ammonia machines are:

Cylinders 42 kg/cm$^2$ hydraulic pressure 21 kg/cm$^2$ air pressure;

Crankcase 21 kg/cm$^2$ hydraulic pressure 10.5 kg/cm$^2$ air pressure.

and for Freon machines:

Cylinders 25 kg/cm$^2$ hydraulic pressure 14 kg/cm$^2$ air pressure;

Crankcase 14 kg/cm$^2$ hydraulic pressure 10.5 kg/cm$^2$ air pressure.

Instead of atmospheric air, hydrogen is recommended for testing Freon machines because hydrogen indicates porosities through which compressed air cannot penetrate.

Further, careful cleaning inside by sand blast, pickling, neutralizing, and proper drying is essential, especially with Freon machines, as any trace of humidity left causes severe disturbance when the machines are put into operation.

It is also recommended to remove air from the inside of Freon compressors by means of dry nitrogen in order to prevent rusting during transport and before erection. Even a small formation of rust causes severe troubles; it is removed by the chemical action of Freon and collects in the filters at the expansion valves.

In short, a compressor for refrigeration must not only be properly designed but it must be most carefully manufactured, tested, and cleaned if it is to work properly.

## CONDENSERS, EVAPORATORS, ETC.[2]

The machinery for any kind of cooling plant includes additional equipment besides the compressors, such as different types of condensers, evaporators, oil-intercepters, receivers, surge drums, etc. The variety is so considerable that even a brief review would exceed the scope of a single short chapter. In general the design of existing types is adequately described in the available literature, and a detailed description is superfluous.

However, the very important question of heat transfer in the various kinds of heat exchangers, such as condensers and evaporators, deserves more thorough examination. A considerable portion of the data furnished in the literature is rather inaccurate, and it is often difficult to determine what figures should be adopted when designing such equipment. Some new information on this subject, together with a very brief description of modern types of apparatus and some practical hints concerning the use of them, is presented below.

All over the world, most of the larger-size stationary plants used for food preservation are constructed for the use of ammonia as a refrigerant. Only in special cases have Freon refrigerants been adopted for machines larger than some 50,000 to 100,000 normal calories per hour. Refrigeration on ships is an exception; in this field Freon now is in general use, even for the largest installations. But transport cooling, and the smaller types of commercial plants, are considered below.

Heat-exchange equipment is a big item in the cost of a refrigeration plant, in most cases amounting to considerably more than half of the total expenditure for machinery. At the same time, it decisively influences the capacity and running cost of the plant. Inefficient operation in most cases is caused by inefficient heat-transfer equipment.

### Condensers

The condenser of a refrigerating plant deprives the gas of the heat absorbed in the coolers and the heat equivalent of the compression energy. The condenser must therefore be calculatd for some 120 to 140 percent of the normal cooling capacity, under ordinary working conditions.

Condensers for larger-size plants are made in two general types, the water-economizing condenser and the directly water-cooled condenser. The dry type air-cooled condenser is used only for very limited capacities and hardly at all for ammonia systems.

As the name implies, the water-economizing condenser is used where

[2]Based on a paper presented by G. Lorentzen.

water is scarce or expensive. The classic type is the atmospheric condenser which consists of a bulky nest of coils erected in the open air.

In order to increase the heat transfer coefficient on the ammonia side of very long coils, different kinds of bleeder systems have been developed. Nevertheless, outside cooling by water evaporation is very limited and greatly dependent on weather conditions. On calm days with moist air the capacity is greatly reduced as compared with windy and dry days. In cold climates there is often considerable trouble with frozen water pipes in water. The maintenance of an extensive pipe system constantly exposed to water and air is expensive and inconvenient.

In general the k-value used for rating this type of condenser lies between 200 and 300 kgcal/hr m² 0° C. For certain bleeder types this figure is doubled and even trebled. These figures are, however, based on using an excess of cooling water, which very much reduces the advantage of using this type of condenser. If the condenser is operated as a real water-economizing type, using no more water than that actually evaporated plus the unavoidable waste (some water has to be drained off to prevent scaling), then the capacity is considerably reduced. The surface required for cooling the water by evaporation is much larger than necessary for transferring the heat from the pipe to the water, and piping is an expensive kind of surface for water cooling. The required additional surface can be obtained, however, by inserting wooden bars between the pipes or by combining with a spray cooler of some kind. Under such circumstances it is preferable to use an ordinary direct water-cooled condenser of, for instance, the shell-and-tube type, in conjunction with a back-cooler for the water. This arrangement has been adopted in many new plants.

The modern *evaporative condenser* has been developed from the old-style atmospheric condenser. The general working principle is the same, but the air is circulated over the coils by means of fans. Eliminator plates reduce the loss of water to a minimum. The construction is very compact, and the condenser is a self-contained unit easily adapted to various locations. If desired, it can be placed inside a building and be connected by ducts with the outside air. The ducts should then be so arranged as to improve the draft through the condenser. The pipe coil, the housing, and other parts exposed to water are usually galvanized in order to reduce upkeep. In some cases trouble has arisen on account of coils, eliminators, and fans scaling up heavily, making frequent cleaning necessary. It is important therefore, that all parts be easily accessible. In some designs the fan is located on the inlet side, pressing the air through the coil, in order to prevent moisture from entering the fan. The condenser housing in that case will be subject to inside pressure, with greater risk of water leaking through.

The calculation of a condenser of this type is generally done on the basis of a temperature difference corresponding to condenser pressure on one side and a wet-bulb temperature of the surrounding air on the other. Since it is the difference in water vapor pressure between water surface and air that is of importance for the cooling by evaporation, the k-value depends greatly on the actual temperature level. According to practice in the United States the condensers are usually rated at a condensation temperature of about 40° C. The k-value at this temperature is then about 240 kgcal/hr m² 0° C., with the usual air velocities.

It is evident from the foregoing that the water-economizing condenser of ordinary construction is not well suited to colder climates. The cooling of the water by evaporation requires much more surface than the transfer of heat from condensing gas to the water. The use of a separate back-cooler and an ordinary closed condenser is often a better solution.

In the second main type of condensers, the directly water-cooled type, the water mostly flows inside tubes, while the gas is condensed on the outside. A common construction is the open vertical shell-and-tube type. The water is distributed by means of special distributors inserted in each tube, which give a spiral motion to the water. The over-all coefficient of heat transfer for this type of apparatus ranges from 700 to around 1,400 kgcal/hr m² 0° C., depending on the quantity of water circulated per pipe. The heat given off to the air passing the pipe is negligible, but the water consumption and the pumping head are comparatively large.

The vertical type shell-and-tube condenser can be erected in the open air and require very little space. The tubes are easily cleaned—an important feature. However, some people are of the opinion that the mixing of water and air in the tubes is likely to accelerate corrosion.

The closed horizontal shell-and-tube condenser is more commonly used than other types in Norway. In this type the tubes are coupled in series in order to obtain a suitable velocity of water without too large consumption. The construction varies considerably according to the number of tubes used in each drum. The trend is away from the old double pipe condensers, through 7- and 19-tube types, towards the larger shells for big installations. Heat transfer conditions are very similar from the 7-tube type upwards. The double-pipe type, however, has a lower k-value, due to the liquid collecting on the surface. This type of apparatus therefore is now mostly used as a liquid subcooler. The heat transfer on the gas side depends on the thickness of the film of liquid formed on the surface. It is important that the condenser be so designed that the liquid is removed from the tubes, immediately upon formation and not permitted to trickle

down on the other tubes. For this reason baffles are sometimes used between the tubes.

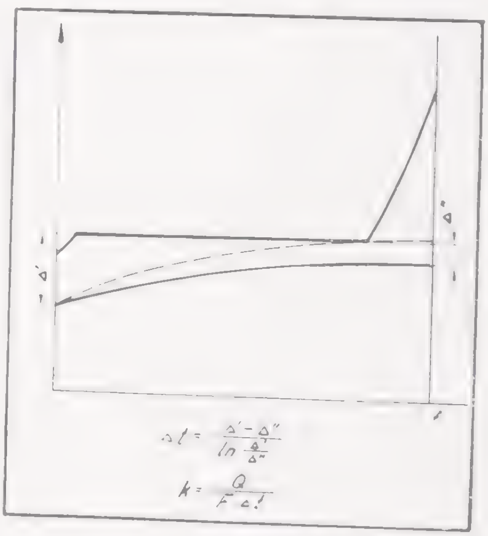
In larger shell-and-tube condensers, the coefficient of heat transfer depends largely on the velocity of the water and the surface conditions of the tubes. The cleaner the surface, the better the heat transfer.

In calculating condensers it is customary to use the logarithmic mean difference of temperature in relation to a constant temperature of condensation on the one side and the changing water temperature on the other. In other words, the superheat of the entering gas and the subcooling of the departing liquid are not taken into consideration. This leads to good results when the temperature split at the water outlet side is not too small, and when the entire tube surface participates actively in the condensation. If the split is decreased below a certain limit, however, part of the surface around the gas inlet may be so warm that there is no condensation in this area. In extreme cases with counter-flow type condensers, the temperature difference at the outlet may be very small and even negative, as indicated by the dotted curve for the water temperature. Tests run under such conditions, with a very low heat load, give far too high k-values and the basis of the calculation thus becomes false. This may be the reason for some of the rather high figures given in the literature.

The lowest curve in the heat transfer diagram (Figure 19) originated from a condenser which was fairly clean; the reason for the high heat-flow resistance was the presence of air in the system. The air not only increases the total pressure on the high side system by its partial pressure, but the main effect is due to the insulating property of the air. The air is brought to the surface of the pipes by the constant flow of refrigerant gas. As the refrigerant is condensed, the air remains in a layer around the pipe, thus hampering the transfer of heat, i.e., in this instance the diffusion of the refrigerant gas to the cold heat exchange surface.

In the past the air was blown off through a valve at the highest point of the system. At the same time an uncontrollable amount of ammonia was lost. According to

*Figure 19. Temperature difference of counter-flow condenser.*



various books, the reason for blowing off the air from the highest point is that the air would gather there during shut-down periods. Actually, however, air and gaseous ammonia are present in mixture all over the available space in a proportion depending on temperature, with comparatively more air when the temperature is low. The air should, of course, be blown off from a point as far from the liquid level as possible, i.e., near the compressor discharge. The gas from the evaporating liquid in the receiver drives the air-refrigerant mixture out when the pressure is lowered through the opening of the blown-off valve.

In modern plants of larger size the air is usually drawn off during operation by means of a purger. The air-refrigerant mixture is generally taken from the top of the receiver, where a comparatively high percentage of air is present above the cold liquid surface. The greater part of the ammonia is condensed on the cooling coil of the purger, leaving the air to be blown off through a manually operated or automatic valve. The whole device is very simple and it is easy to purge the system almost completely of noncondensable gases. A purger is, for obvious reasons, particularly desirable in plants operating below atmospheric pressure on the suction side.

Another purging device is built around the cold suction line, which takes the place of the cooling coil. Otherwise, the system is exactly the same, except that a high side-float valve is used for draining off the condensed liquid from the purger into the suction line. Strange to say, purgers of this type are not often used in Freon plants, where the need of them should be even more pronounced, in order to reduce losses of refrigerant during purging. It is more difficult to determine how much Freon is actually lost during the blow-off operation, for it cannot be smelled, as ammonia can. The gauge-controlled, refrigerant-saving purge therefore offers considerable advantages in the Freon-field also.

As has been pointed out, the temperature difference in the condenser is of great importance to the operating cost of any plant. It is therefore advisable to hook up the condenser in the piping diagram in such a manner that the entire surface may be utilized, regardless of the number of compressors in operation. A parallel hook-up of the condensers is better than the usual one condenser for each compressor or each evaporator system. In one case, the high-side piping plan of a fairly new plant was changed, altering it from single purpose condensers to a parallel connection, and by that simple adjustment saved as much as 25 percent of the average total power consumption, without increasing the condenser surface. This is worth bearing in mind when preparing pipe diagrams for plants with variable cooling loads for different purposes.

The size of the condensers to be used under given conditions should be determined from the viewpoint of economy. The factors to be

considered are power cost, cost of condenser per square meter, running time, cost of cooling water, etc.

### Evaporators

As regards construction of evaporators, very much the same factors must be borne in mind in order to arrive at an efficient apparatus. In the condenser it is essential that the liquid ammonia be removed from the heat-transferring surface as fast as possible. In the evaporator the gas which should be removed in the shortest possible time in order to establish the best possible contact with the boiling liquid. As in the condensers, the main resistance to the flow of heat is mostly found not on the side of the refrigerant, but on the side of the cooled medium. The most effective way to augment the capacity of any type of cooler is therefore to increase the velocity of the cooled medium at the cost of a bigger pressure drop and increased power consumption by fans or pumps. The construction of the coolers depends to a large extent on the properties of the medium to be cooled, in most cases some kind of brine, or air.

There are two general types of brine coolers used in larger installations, the shell-and-tube type and the coil type. *The shell-and-tube evaporator* is of the same general construction as the corresponding condenser; in ammonia plants it is flooded in most cases. For Freon installations larger units are sometimes built for recirculation by means of a low-pressure Freon pump in order to reduce the charge and improve heat transfer.

The shell-and-tube cooler is readily adaptable to a closed brine system which has the important advantage of reducing corrosion: The oxygen content in the brine is decreased on account of the reduction of the contact surface with the air. The same pump can be used both for general brine circulation and for circulation through the cooler. The space requirement is limited, and the tubes can easily be cleaned and replaced if necessary. As for the condensers, enough room must be provided for cleaning and renewal of tubes. The heat-transfer characteristics are very much the same as for the shell-and-tube condenser, the velocity of the brine in the tubes being the most important factor. The efficiency increases rapidly with the brine velocity. This increase, of course, takes place at the cost of a higher pumping head and higher power consumption.

In the condenser, the heat-transfer factor of the refrigerant side is reduced as the heat load increases due to the higher resistance in the condensed liquid film. In an ordinary evaporator with self-circulation, however, the heat transfer improves with increased heat load, owing to better circulation of the liquid.

Coil-type brine coolers are built in a great variety of forms. One of the main considerations in design is getting a good circulation

of liquid inside the pipes. The higher the heat load per unit of surface, the shorter the individual pipes should be. The coolers should be constructed so as to have good and positive circulation of the liquid. At the same time they should have a compact type of coil in order to get the best possible velocity between the pipes without requiring agitators that are too large. The velocity obtained has, of course, a great influence on the heat transfer.

The over-all k-value obtained in the better type flooded coil brine coolers lies in most cases between 300 and 600 kgcal/hr $m^2$ 0° C. according to brine velocity and temperature. The velocity generally runs up to 0.5 m/sec.; under such conditions it varies between 400 and 500 for low-temperature work.

## Cooling Coils

Air coolers may be of the direct-expansion or brine-cooled type. The direct-expansion system is now generally used in new plants. Construction of the coil does not vary much in the same type of coolers. As the heat transfer resistance is in most cases concentrated on the air side of the pipe wall, the k-value is for all practical purposes the same in both systems, if the direct-expansion system is properly designed.

Air coolers may be divided in two groups, depending on the means used for moving the air along the cold pipe surface. There are forced-draft coolers or cold diffusers, variously named by the trade, all using one or more fans to force the air through the cooler. In addition there are the ordinary pipe coils for free convection cooling of cold storage rooms. Besides the so-called "dry" coolers there are also the "wet" coolers which cool air through direct contact with a spray of brine. These coolers may be either of the forced-draft or the natural-convection type, but the latter is gradually disappearing.

The ordinary forced-draft air cooler is a closely nested pipe coil through which the air is blown by axial or centrifugal fans. Formerly the air was mostly blown along the longitudinal direction of the pipes, but now many coolers are constructed for circulation at a right angle to the run of the pipes, which results in a considerable increase of heat transfer per unit of area.

The heat-transfer factor depends on the air velocity as well as on frost formation on the coil. The highly efficient cross-blown coolers are very sensitive to frosting. Under otherwise equal conditions the thickness of the frosting is greater as the total surface is smaller. The same thickness is more detrimental in proportion as the heat load per square meter is higher. If this type of air cooler is used below freezing, it is of the greatest importance to have an efficient and easily operated defrosting system. There are several of these systems in use, the

most common being hot gas defrosting for direct-expansion installations. Water defrosting may be practical in many cases; it is very efficient when properly designed. Brine is also being used in some instances. One company uses a glycol mixture which circulates continuously over the finned coils. A special still is used to reconcentrate the defrosting liquid.

The heat-transfer factor varies considerably, according to the construction of the cooler and the ducting. It is never possible to get an even distribution of the air velocity over the entire cross section. Anemometer tests in many coolers have shown that the greater part of the circulated air does not pass the coils at all, but escapes through openings at the sides and particularly between the coil and the water collecting underneath it. What is really important is the velocity between the pipes. For flooded cross-brown coolers with very little frosting, *k* varies between about 20 kgcal/hr m² 0° C. by an actual average velocity between pipes of 2.5 m/sec. up to about 35 at a velocity of 6 m/sec. In these cases the velocity, as calculated on a basis of the capacity of the fan and even distribution, was considerably higher. In practice it is advisable to use somewhat lower factors and to take into consideration the frosting of the coils.

Modern types of forced convection coolers are often, even for larger jobs, made as self-contained units. The coil and the centrifugal fans are enclosed in a sheet-metal casing. The surge-drum and float-valve hook-up is visible on the left side.

For cooling of freezer storage-rooms, still-air-cooling by means of coil grids has certain advantages. The coils are placed under the ceiling, or on the walls, or quite often at both places. It is, of course, important to have the coils evenly distributed and located preferably along the warmer walls.

There is some difference of opinion regarding the heat-transfer capacity of the usual cooling coils. While in the United States of America the coils are calculated with a k-value of 8 to 10 kgcal/hr m² 0° C., in Europe nearly double these figures are being used for the same type of coils. A study of this problem on the basis of well-known general formulae for heat transfer coefficients by free convection, radiation, and moisture diffusion indicates nearly the same heat transfer as the United States figures now in general use.

Tests carried out on different types of coils to check the theoretical calculations indicate that the k-factor varies considerably according to how the coil is fitted, the extent of frosting, etc. If free circulation of air is restricted, the heat transfer by convection may be considerably reduced. Baffling also has a tendency to reduce the heat exchange by radiation.

The different types of air coolers may be made of finned coils in order to bring more balance in the heat transfer resistance inside and

outside the coil. Plate-type coolers are also used, but space does not permit a further discussion of the many problems involved.

### *Expansion Systems*

It is very important in all types of evaporators that the heat-transfer surface be entirely wetted with refrigerant. In the "dry expansion system" a good portion of the coil is often operated at reduced efficiency owing to insufficient wetting of the surface near the outlet end. In many cases efficiency has been reduced more than 25 percent. Considering the cost of coils, an operation of this kind is far from economical. The trend is therefore definitely towards the "flooded systems" for all larger-size ammonia plants.

The flooded system is characterized by the use of a liquid intercepter or surge drum to separate the gas and liquid coming from the cooler. The surge drum must, of course, be located above the cooler or at least level with it. The liquid is recirculated in the cooler, either by natural convection or by means of a low-pressure pump. If a pump is used, the drum may be placed underneath the cooler or even in the engine room.

Designing the liquid line requires great care and skill. The bad reputation of direct expansion systems is always due to poorly designed liquid systems. In designing new and complicated plants, close attention should be given to solving these problems.

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# 6. Methods and Apparatus for Commercial Freezing[1]

## FREEZING SYSTEMS

A CENTURY ago foods were frozen by keeping them in a closed refrigerated space or by leaving them outdoors in cold weather. There was no way of keeping frozen foods beyond the winter months. Freezing was of interest as a means of keeping foods through the winter and in moving foods which were frozen in the north in the winter to points farther south. Even today, freezing in still air is used to freeze an amazing quantity of products. If the packages are not too large the quality of many foods is still very good if they were strictly fresh and of high quality at the time of freezing. However, many improvements have been made in freezing processes.

The first improvement was to create a man-made cold wind, or air blast. The principle is simply that rapidly moving cold air takes the heat away from food and freezes it fairly rapidly. The rate of freezing depends upon the temperature of the air, the rate of its movement, and the way the food is packaged. In an air blast a single pea freezes in five or ten minutes at −18° C. At a lower temperature it freezes even faster.

A third method of freezing is the original quick-freezing system, brine-freezing. It is not necessary to move a great quantity of brine, as in the case of air which has a very low specific heat.

Then, there is the Birdseye system. Others had used the general principle before—of freezing in contact with metals. P. W. Petersen was one of the first in the United States of America to freeze food by placing it in a refrigerated metal container, following the well

[1]Based on a paper presented by D. K. Tressler.

known method of making ice by putting water in galvanized cans immersed in brine at a relatively low temperature, causing the fast freezing of water into ice.

### Freezing in Contact with Metallic Surfaces

A. H. Cooke puts food into recessed metal molds and circulates brine around the molds, quick-freezing the food. That is close to the Birdseye system, which involves freezing packaged food between movable metal surfaces. In the original Birdseye system there were two long belts, one superimposed upon the other. The belts moved in one direction carrying food through a tunnel. Cold brine was sprayed down the upper belt, which overlapped the lower, and the brine cascaded into a tank. Brine was also sprayed up on the underside of the lower belt, cooling it to a low temperature. By that system it was possible to freeze packages of fish 5 cm. (2 in.) thick in one and a half hours or a little less to a temperature of —18° C.

The more recent Birdseye system, and a number of its imitations, have movable metal plates, moving only in a vertical direction, superimposed one over another and so arranged as to make shelves on which trays of packaged products are placed. When the plates are all covered by products, they are closed by a hydraulic arrangement and held under a limited uniform pressure. The plates are hollow and connected by rubber hose to a liquid ammonia supply. The liquid ammonia runs into the hollow plates, chilling them to about —30° C.

### Freezing on Vacuum Plates

In more recent years, many systems of freezing food on thin-walled metal plates have been used, largely in the locker plants. Ammonia, or more commonly, Freon 12, is allowed to expand inside these plates, cooling the product rapidly on one side. By this system a fairly rapid freeze is obtained, but only at approximately one-quarter the rate achieved by the Birdseye system—freezing by conduction from both sides is approximately four times faster. Actually this Kold Hold or Dole Plate system is not very different from the old fashioned sharp-freezing system used in the United States for many years.

### Sharp-Freezing

In sharp-freezing, products are frozen on shelves made of coils in which refrigerated brine is circulated (if it is an indirect system) or in which ammonia is allowed to expand (if it is the direct system of freezing). The coils are refrigerated to about —30° C. and

theoretically there is rapid freezing of the food. Actually, with a round coil there is relatively little surface for the tray or pan on which the food is placed to touch the metal. Further, since the products are placed in pans each holding about 14 kilograms, freezing is relatively slow because of the size of the packages or pans.

For freezing large fish like halibut or very large cod, the coils are first covered with galvanized sheet iron, on which the fish are placed. However, freezing is relatively slow, because it is from one side only, because the contact of the metal with the coil is poor, and because the coil is soon covered with ice. This system is still extensively used in the United States to freeze fish. In fact, practically all of the round or whole fish are frozen by this method. However, the system has been improved recently by use of an auxiliary air blast.

### The "Rotofroster"

One of the systems which has come into limited use in Boston, Mass., U.S.A. is the Jackstone "rotofroster," which consists of an insulated cabinet containing 24 pairs of freezing plates, mounted substantially parallel, radiating out from and attached to a rotating drum axis. Brine or ammonia is circulated through the plates from the distributor chamber in the drum. As the drum axis rotates, a pair of plates arrives at the loading slot and automatically spreads apart. The product to be frozen is usually put on a tray and a trayful of products is placed between the plates. As the loading door shuts, the drum rotates, bringing another pair of plates in line for loading. When the froster is completely loaded, the first plate to be loaded has made a complete revolution and has been completely frozen. The tray of frozen products is removed and a tray of unfrozen products put in. This system freezes the product rather rapidly by contact with metal plates. Its use is limited chiefly to the freezing of relatively thin packages of food, all of uniform thickness.

### Brine Freezing

In Canada some freezing is done by immersion in or by pumping brine around and around the product. In some plants fish are put in rubber latex bags and the brine pumped around them. This system has not been used recently in the United States.

The so-called fog-freezing process ("Z" system) is in use in Long Island, New York, U.S.A. for the freezing of ducks, but not of other products. The fog-freezing process has the advantage that it does not desiccate the product, as a blast of air does, but coats it by circulating over it a blast of fog. Actually as the brine is circulated round and round, it picks up particles of food which won't go through the spray nozzle, so it is necessary to filter the brine. Another disad-

vantage of the "Z" or fog system is that relatively few packages can stand contact with the brine fog without becoming soiled.

Two new systems of freezing food by immersion use invert sugar syrup instead of brine. These two processes are called the TVA (Tennessee Valley Authority) or Taylor system and the Bartlett system. The former is still used for freezing strawberries. Some units have been built on the Mississippi River for freezing strawberries which are brought in from farms along the river. The strawberries are conveyed through a tank of refrigerated invert sugar syrup, which has a relatively high capacity for absorbing heat. The strawberries are frozen in five or ten minutes. The berries are then placed in a basket centrifuge and whirled rapidly to remove the sugar syrup. This system provides an excellent quality of strawberries, which do not need to be immersed in syrup during storage. However, when these strawberries are kept in storage for three or four months, in the course of which there is a natural fluctuation in the temperature of the storage, the small crystals of the rapidly frozen product increase in size. Certain other changes take place, and the frozen strawberries are altered to a product no better than that frozen by air blast or by other methods. About five years ago, at the University of Texas, Bartlett invented a somewhat similar system of freezing berries, with the use of a somewhat colder sugar syrup containing very fine crystals of ice. In this polyphase system the first phase is the liquid, the second the ice crystals, and the third vapor. The strawberries or other products put through this syrup freeze rapidly. Shrimp are frozen in sodium chloride brine which contains very fine ice crystals. Bartlett maintains that when food is frozen under these conditions, there is very little penetration of salt.

The trouble with these systems is that the circulating brine or syrup becomes contaminated with the product being frozen, thus yielding an undesirable product which may have a high bacteria content, a bad odor, and perhaps a bad flavor. In the case of strawberries, the flavor from the syrup is not undesirable, but invert sugar syrup is expensive and many tons must be used. Before very long the syrup becomes so diluted with strawberry juice that more and more must be added in order to maintain the required concentration of solids.

## *Improved Sharp-Freezing Processes*

The sharp-freezing process has been improved during the past decade. The principal improvement has been the use of air blast in combination with the sharp freeze. The product is frozen in shallow pans or trays, placed on refrigerated coils, and subjected to blasts of refrigerated air. If a temperature of −30° C. is used, freezing is fairly rapid. Very large quantities of all types of products are frozen

by this improved sharp freeze method. It has most of the advantages of an air-blast system and all the advantages of the old sharp-freeze system. Thin metal Dole and Kold Hold plates are sometimes used in place of coils, refrigerated to —30° C., and subjected to an air blast of —25° to —30° C. If the product is not packed in too large packages, a rapid freeze results.

The Murphy freezer is very much like the sharp-freezer using air blasts, with this difference: Instead of ordinary round piping, pipes with a rectangular cross section are used as shelves. The trays have almost perfect contact with the refrigerated metal surface, and to this is added a rapid blast of refrigerated air over the products being frozen. This system is used only in the state of New Jersey (U.S.A.) but the installation is very large and is part of one of the largest food freezing plants in the world. As much as 27 million kg. (60 million lb.) of foods per year are frozen on a single farm, using the Birdseye and Murphy systems.

## Air-Blast Freezing Systems

The original air-blast system, which is still in use, involves merely the placing of the products on shelves or racks in a large refrigerated room in front of a large portable fan. Many of the cold-storage warehouses in the United States offer to quick freeze food by the air blast system. The method has been improved by adding tunnels in which the air is refrigerated by passing it over finned coils and then over the food, after which it is recirculated. According to a new system, cold air is forced up through vertical tunnels around trays in which products are being frozen. By another system the air is refrigerated, blown over the products, refrigerated again, and recirculated many times.

As a result of the demand for "free-flowing" frozen vegetables, long woven metal freezing belts have been constructed in order to produce this type of product. Air blast is refrigerated to about —30° C., and blown up through these belts on which loose peas are placed. The peas, if not placed in too deep a layer, are frozen in approximately ten minutes. However, they are usually left in the freezer for about 15 minutes, or as long as it takes to convey them from one end of the tunnel to the other, a distance of 15 to 25 meters. Before freezing, peas are always blanched or scalded, then cooled in cold water. They are very wet when placed on the belt and freeze more or less into a solid mass. When the frozen peas fall off at the far end of the belt, a rotary breaker is used to separate the frozen mass into individual peas.

In some instances the peas are immediately packaged for retail, but the usual practice is to put them in large drums in refrigerated rooms, where they are held for packaging until labor is more

plentiful. This method is very generally used for peas, cut beans, lima beans, and sweet maize (frozen whole-kernel maize is of considerable commercial importance in the United States). Because of their irregular shape, the method cannot be used satisfactorily to freeze unpackaged asparagus, broccoli, cauliflower, or spinach.

Packaged products are also placed in air-blast freezers and slowly moved through tunnels. By another system, packaged or unpackaged vegetables and other products are placed on trays of wire mesh which move up through a vertical air-blast tunnel. When the packages or loose vegetables reach the top of the stack or tunnel, the trays move horizontally to a point where they are removed and new products put in. Two systems of this type, the Greene and York systems, vary slightly in mechanical arrangements.

## ADVANTAGES AND DISADVANTAGES OF THE VARIOUS SYSTEMS

If packaged foods are frozen in still or slowly moving air, the packages bulge out of shape. The product is frozen very slowly so the package must be small if a high-quality product is to result. Thirdly, if the products are not packaged, considerable desiccation occurs. The advantage of such a process is that it is relatively cheap. The product is merely placed in a room for a period of time and then moved out. Owing to the fact that freezing is so slow, such a process is ordinarily used only for products which are to be sold at wholesale and not for the so-called quick-frozen food to be sold at retail.

If unpackaged fruits or vegetables, fish, or other foods are frozen in an air-blast system, the surface of the food becomes desiccated. Only water is lost, but it is deposited on the refrigerated coils, which is a disadvantage. If unpackaged products are frozen, two blast systems may be required in order to have one available for work when the coils require defrosting. The loss of moisture from the surface of the food is more serious than loss of weight, because the desiccated surface is then exposed to oxygen of the air and there is oxidation of fats, loss of flavor, and many other undesirable changes.

Unpackaged products frozen in an air blast do not keep nearly so long at a given storage temperature, other conditions being the same, because the surface dries out and the products are left exposed to the oxygen of the air. One way of avoiding this is by doing what has been done in fish freezing, i.e., by glazing. As the product passes through the ice breaker, a small amount of moisture may be atomized on the product and a thin layer of ice formed over each piece of food. This helps to counteract serious desiccation during storage.

It may seem that if products were stored in tight containers and

later packaged in a moisture-vapor-proof package they would lose even less weight. That may be good theory, but it is not good practice. Products frozen first and then packaged do not fill the voids, so each package contains a great deal of air. When peas, for instance, are soft and limp, they pack down and fill up most of the space in a package. When they are packaged after freezing, a package opened some months later has all its interstices filled with snow—this snow is some of the moisture from the peas, representing weight lost by the product.

Why does this happen during storage? In most cases, temperatures in cold storage fluctuate between −20° and −18° C. Air at −20° C. holds less moisture than air at −18° C. When the product is cooled to −20° C. a deposit of snow forms inside the package as fine crystals in the interstices. When the product warms to −18° C. moisture comes out of the peas and builds on the fine crystals. Packaging the product when wet and then freezing is better, because the film of moisture freezes over the product; and since there is relatively little air in the interstices and relatively little opportunity for this "pumping" effect.

The air-blast system is excellent for packaged goods, but it is relatively slow. Individual peas or cut beans put in an air blast freeze in five to ten minutes, but in a package it takes four hours or longer. However, this rate of freezing is fast enough to prevent deleterious action by micro-organisms during the freezing process, and should stop undesirable chemical actions.

A 12-ounce (340.5 g.) package of peas in an air blast takes from four to six hours to freeze, which is fast enough, but if the package is filled completely and frozen in air blast a bulged package results. If the package is not filled completely, to avoid bulging, head space is left in it and trouble results from desiccation and the "pumping" effect. Furthermore, a slight larger size of shipping container is required for the same amount of product.

What are the disadvantages of the brine system? The difficulties encountered when the brine is sprayed directly on the product have already been indicated. Why not package first? Because few packages can stand spraying with syrup or brine. However, tin and glass containers have been used quite satisfactorily. If not completely immersed, and if there is no possibility of brine getting in through the top, rubber latex bags can be satisfactorily sprayed with brine, but the brine system has great limitations for freezing packaged products.

A disadvantage of the Petersen system, in which the product is frozen in long tapered cans immersed in a tank of refrigerated brine, is that a great deal of labor is involved in packing the products into the cans. Another is that the products must fit into one size of can. Further, the products expand a little during freezing and it is diffi-

cult to get them out of the cans, usually resulting in some damage to the wrappers.

Two of the most important methods of freezing are sharp-freezing and sharp-freezing plus air blast. These systems are generally used for fish fillets, but are not used much for high-grade fillets—the packages bulge slightly and do not look neat. Sharp-freezing fillets in pans usually takes 20 hours; they are frozen so slowly that they lose much drip when thawed. The same holds true for freezing on thin metal plates by the Kold Hold and Dole systems. However, one advantage of these systems is that any size of package can be used.

The great disadvantage of the Birdseye system is that all packages on a single shelf must be exactly the same thickness and preferably of the same size and shape. Turkey cannot be frozen in a Birdseye Multiplate Froster as rapidly as a packaged product of equal size, having a flat-surfaced top and bottom.

The Jackstone freezer has even greater disadvantages because it requires an exact number of trays of products of uniform thickness fitted into a space, making it virtually impossible to freeze packaged fillets and chickens at the same time. Roasting chickens do not fit well into the Jackstone freezer. They can be frozen in the Birdseye freezer, but are flattened by the pressure, resulting in a product of poor appearance. Disjointed chicken (cut into pieces for frying or fricassee), however, can put into a package with a moisture-proof lining and frozen in either a Birdseye or a Jackstone freezer.

The best freezing system depends upon the product, the size of the package, where it is to be sold, how it is to be marketed, the kind of material in which it is to be packaged, and how it is to be stored. After this information is available, a good way of freezing can be indicated but there is no best way. Each process has certain advantages; each process has many disadvantages.

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# 7. Packaging Materials[1] and Machinery

## WATER-VAPOR-PROOFNESS

THE FIRST REQUIREMENT of good packaging is the best possible protection of the refrigerated food against external influences. The most perceptible influence to which frozen food is exposed is dehydration. This results from the removal of water from the surface of the food because of the low humidity prevailing in low-temperature rooms. Dehydration causes loss of weight coupled with deterioration of quality, including changes in color and texture.

Under unfavorable storage conditions this loss can be very considerable, as shown in Table 1. In these experiments the parchment substitute had a very high water-vapor permeability and the heavy wax paper permitted loss of weight because it was not sufficiently flexible to be wrapped close to the surface of the cod fillets and protect them from the air circulation in the storage room. The loss is also significant when cardboard containers are used as shown in Table 2. In practice, where all six sides of the cartons are seldom exposed to the drying air, losses of course are less.

The package in general use today for retail packing of frozen foods is a folding rectangular box made of wax-treated cardboard, provided with an inner liner, as a rule not heat-sealed, of material such as water-vapor-proof cellophane. The container often (but not always) has an outer wrapping of, for example, sealed wax paper. This type of package is not sufficiently water-vapor-proof for lengthy storing of most products. It would be possible to make the packaging more water-vapor proof by providing a heat-sealable inner bag, (but

[1]Based on a paper presented by M. Kondrup.

Table 1.—Loss of Weight[1] of 12-Oz. (340.5 G.) Cod Fillets in Different Wrappings

*Freezing:* 3 hours, —35° C. air velocity 10 m/sec. (2,000 ft/min.).
*Storing:* —18° C. forced air circulation.

| Wrapping | Loss of weight in | |
|---|---|---|
| | 3 months | 4 months |
| | *Percent* | |
| Parchment substitute 20 g/m² (1 layer) | 20.5 | 24.0 |
| Parchment substitute 20 g/m² (2 layers) | 13.5 | 16.5 |
| Heavy two-side waxed paper 100 g/m² | 11.0 | 14.5 |
| Cellophane MSST 400, 45 g/m² | 0.5 | 0.8 |

[1] Source:—Danish Refrigeration Research Laboratory. Based on unfrozen weight.

this would reduce the packing speed, which is already unsatisfactory) or by using a heat-sealed outer wrapping of a material more water-vapor-proof than waxed paper (for example, moisture-vapor-proof cellophane).

The package should have at least one layer of a material having low water-vapor-permeability. At −15° C. vegetable parchments have a water-vapor-permeability (WVP) of about 30 g/m²/24 hr. and waxed papers 5 to 8 g/m²/24 hr. Special coated papers, moisture-proof viscose sheets, and thermoplastic films are highly water-vapor-proof. To this group belong films made of regenerated cellulose coated with lacquer containing nitrocellulose such as cellophane MST and MSST, and also films made of polyvinylidenechloride (for example, Saran) and polyethylene (for example, Visqueen). Furthermore, films on a rubber base such as Pliofilm, a rubber hydrochloride derivative, have high resistance to the penetration of water vapor. Tressler and Evers state that for special coated papers WVP is 0.3 to 0.6, for moisture-vapor-proof viscose films 0.2 to 0.4 g/m²/24 hr. Thermoplastic films have WVP like moisture-vapor-proof viscose films or less.

But metal foils are still better. They can be employed either as such or as laminates with various thermoplastics. Metal foils, however, must have a certain thickness before they are free of pinholes. Aluminum foil, as an example, must have a thickness of 0.023 to 0.026 mm. in order to reduce its water-vapor-permeability to zero. Metal cans or other metal containers, which are ideal for water-vapor-proofness, have hitherto, for various reasons, been used only in large-sized cans or drums of, for example, 19 liters or 13.5 kg. (5 gal. or 30 lbs.), especially for fruits for further processing later, and for retail packaging of special products such as orange juice. Metal containers have in recent years, however, found increasing application, particularly in the form of flat parallelepipedic cans.

TABLE 2.—LOSS OF WEIGHT[1] OF 12-OZ. (340.5 G.) FROZEN COD FILLETS IN CARDBOARD CARTONS

*Contents:* Crushed ice.
*Storing:* —20° C. Some air circulation, all six surfaces free.

| Type of container | Loss of weight in 2 months |
|---|---|
| | *Percent* |
| A. End opening experimental carton: 180 x 115 x 60 mm. light waxed; inner bag of moisture-vaporproof, heat-sealed cellophane | 0.4 |
| B. Same as A, but inner bag of medium waxed paper, not sealed but closed by folding | 4.3 |
| C. Top-opening carton: 160 x 95 x 30 mm. light waxed; unsealed inner lining of MVP cellophane | 0.7 |
| D. Top-opening Peters type carton: 10 x 5 x 1¾ in. (about 250 x 125 x 45 mm.), heavy waxed; unsealed inner lining of MVP cellophane | 0.4 |
| E. Top-opening Peters type carton: 5 x 4 x 1½ in. (about 125 x 100 x 40 mm.) heavy waxed; unsealed inner lining of MVP cellophane | 0.5 |
| F. Same as E; no inner lining but heat-sealed outer wrap of MVP cellophane | 0.2 |
| G. Same as E; no inner lining but heat-sealed outer wrap of Visqueen film | 0.0 |

[1] SOURCE: Danish Refrigeration Research Laboratory. Based on weight of contents after freezing.

Although a packaging material may be completely water-vapor-tight, the product may nevertheless be dehydrated if the packaging material does not bear well against the surface of the product. When this occurs water-vapor is transferred from the product to the inside of the coldest wall of the package and results in the formation of ice crystals there.

This problem must also be taken into account in handling poultry or cuts of meat, which should be packaged in flexible materials with a low water-vapor-permeability. The Cry-O-Vac or Cry-O-Pak method employs a bag of special thermoplastic material into which the individual bird is placed. A tight fit of the packaging material against the uneven configuration of the bird is obtained by mechanically evacuating the air, after which the packed product is dipped in hot water, causing the thermoplastic to shrink 60 to 70 percent.

## TESTING WATER-VAPOR-PERMEABILITY

Two methods may be used to test the water-vapor-permeability of a packaging material. In the first instance a product such as meat or

fillet of fish is wrapped or packaged in different kinds of materials and tested for comparison against packaging which has proved satisfactory in practical use. The packages are placed in a low-temperature room and weighed at intervals to ascertain their loss of weight. This method corresponds to practical conditions, but it takes several months, perhaps more than a year, and the data arrived at are difficult to reproduce. In the second instance the water-vapor-permeability is determined under controlled conditions with fixed temperature and humidity, using small samples which can be weighed on a fine balance at relatively short intervals. The results become available in a few days or weeks and are reproducible.

The latter method is well known and widely used. The apparatus required is fairly simple and is described in Standard Methods of the Technical Association of the Pulp and Paper Industry. The material being tested is fastened by water-vapor-proof wax as a lid or cover over a small bowl or petri dish containing a desiccant and providing a relative humidity of approximately zero. The dish is then placed in a room with a constant degree of humidity. This method, however, was devised to determine water-vapor-permeability at 50 percent relative humidity and 27° C., whereas we are interested in temperatures as low as —20° C. Results obtained by a method like this would be of much greater value if humidity conditions were equivalent to those prevailing in ordinary low-temperature rooms with a relative humidity of about 100 percent on one side of the packaging material (as on the surface of the product), and a relative humidity of 70 to 80 percent on the other side (as in the atmosphere of the low-temperature room).

The Danish Refrigeration Research Laboratory is conducting experiments with the device shown in Figure 20. Two circular pieces of the material to be tested are held tightly by three rubber packing rings and two outside metal rings secured to each other by screws, insuring an air-tight fit. In the circular space, between the two pieces of material to be tested (about 50 mm. in diameter) is placed a moist

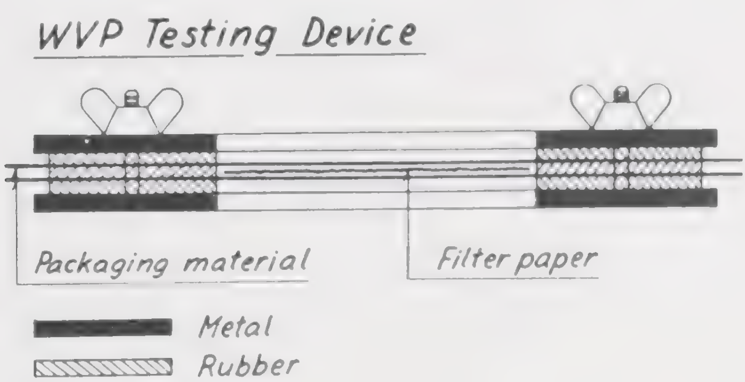


*Figure 20. Device for testing water-vapor proofness of materials.*

piece of filter paper, and when this device is placed in an environment of —18° C. and 70 percent relative humidity, a small model of a parcel of frozen food in a low-temperature room is obtained. In principle the method is the same as that developed by Reichsinstitut fur Lebensmittelfrischhaltung, Karlsruhe, Germany, during the war, except that they simply stamped circular pieces of the material to be tested which were mechanically glued together along the rims and hung up in small racks in a specially constructed air-conditioned testing room. Finally, it cannot be taken for granted that a material which has great water-vapor-permeability at say 50 percent relative humidity and 23° C. has the same water-vapor-permeability at 75 percent humidity and —18° C. It is necessary to determine the water-vapor-permeability under the same conditions of humidity and temperature as those under which the material is to be used in actual practice.

## AIR- AND FLAVOR-PROOFNESS

Frozen food packaging materials must be impermeable or at most only slightly permeable to gases, particularly oxygen, which causes rancidity, and other effects as well as change of color. In general, a good water-vapor-proof packaging must be both air- and flavor-tight.

Sugar, syrups, brine, or even plain water may well be included among protective packaging materials. They all afford protection against dehydration or exchange of vapors and gases. They can, inexpensively, make a poorly protective carton absolutely effective for at least a limited storage period. Frozen whole fish, not packaged, are often glazed by dipping in water or by having water poured over them, providing them with a thin layer of ice which gives excellent protection until in the course of a few months the ice disappears by evaporation.

To measure air-and flavor-proofness is rather difficult; no simple method has yet been devised for this purpose. The Karlsruhe Institute has developed an apparatus for determining air permeability,—a system of capillary tubes, cocks, and manometer tubes with which it is possible during a period of time to keep a fixed pressure difference between the two sides of a sample under test. By this means the quantity of air which passes per unit of time through a fixed area of the material can be determined.

To determine flavor-permeability the Karlsruhe Institute used an apparatus consisting of an air-tight container at the bottom of which is placed a dish containing a scent. The dish is tightly covered with the sample of material to be tested. On a rack inside the container is a dish containing a fluid which absorbs the scent that

has penetrated the sample of packaging material. The amount of absorbed odor can be determined by chemical analysis.

## TEMPERATURE, MOISTURE, RUPTURE, AND ACID RESISTANCE

The purpose of packaging material is to protect the product it covers, but the material is attacked from both within and without.

Packaging material for frozen food must withstand great fluctuations of temperature without changing its characteristics. It should maintain its protective power and flexibility for at least a short time at temperatures of —40° to —45° C. during the freezing period, and at as low a temperature as —30° C. for at least one year. There should be no crystallization to impair its water-vapor-proofness. A special micro-crystalline wax must be used for waxed paper. The adhesive used for sealing the packaging should have keeping qualities and must not dehydrate. If the adhesive in a laminate dries out, air canals appear and there is a severe increase in the water-vapor-permeability of the laminate.

*Figure 21. Tray-type container made from heavy aluminum*

Precooked frozen foods will no doubt result in a great demand for temperature-resistant packaging. The precooked product should be packaged while still hot enough to avoid the danger of infection by micro-organisms. Such packaging must, therefore, bear up to a variation in temperature from as high as 95° C. to as low as —40° C. Thin aluminum trays which can be quickly cooled may provide an answer. (Figure 21.)

If the freezing is done by immersion in a cold liquid mixture, the container must be resistant to the freezing medium. Cans like those used for heat-sterilization of foods satisfy this demand.

*Figure 22. Machine for wrapping rectangular packages. (Courtesy of Hayssen Mfg. Co., Sheboygan, Wis., U.S.A.)*

Packaging material must withstand the humidity developing from hoar frost when the package is removed from the low-temperature room. It must withstand the stresses of handling. Wrappings for meat or poultry must resist ripping or tearing by protruding bones and have the strength to meet the mechanical packing.

## MECHANICAL STRENGTH

Within the package the materials used should resist the action of humidity. For sugar syrups, brine, and several kinds of foods, the inner facing of the package must be acidproof or greaseproof. Many packaging films are inherently waterproof, but others such as cellophane must be coated with a special waterproof lacquer.

As to metal foils or cans, the problems are the same as in the use of cans for heat-sterilized foods: the metal surface must be provided with a protective coating—tin or enamel on iron, or an oxide film or enamel on, for example, aluminum.

The attack of fruit acids can be measured qualitatively by fastening the coating to be tested tightly over a petri dish and placing the dish bottom side up over a piece of aluminum foil. Through a small hole in the turned-up bottom of the dish, lemon juice or a similar acid substance is poured over the coating being tested. After a given time, penetration of the coating can be determined by the amount of corrosion of the aluminum foil.

## PACKING SPEED

Filling and closing are the two basic operations in packaging. Depending on the design of the package, operations such as unfolding,

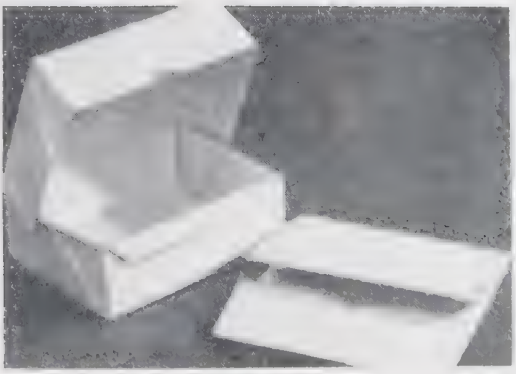

*Figure 23. Carton designed for automatic filling (Courtesy of Marathon Corp., Menasha, Wis., U.S.A.)*

setting up, sealing, and or wrapping must be added. The natural tendency is to restrict the process to the two basic operations, but this is not always possible. It is very difficult to avoid manual work when packing a product such as fish fillets, but efforts are being made toward that end. Figure 22 shows a Hayssen machine which receives hand-packed shrimp and provides them with an overwrap of heat-sealed waxed paper at the rate of 50 packages per minute. To increase the packing rate, the cartons must be specially designed for machine packing. The Marathon Corporation carton shown in Figure 23 which is shipped flat, is difficult to set up by hand. But placed on the machine shown in Figure 24, 80 to 100 cartons of peas can be packed per minute. This machine made by the Food Machinery Corporation is one of the newest developments in packaging machinery. It is intended for packing free-running, frozen, or unfrozen products such as peas or cut beans. The cartons are stacked into a magazine from which they are automatically removed, opened, and carried up under a revolving filling table, which automatically measures the volume of the product to fill the cartons. From the

*Figure 24. Filling machine for use with carton shown in Figure 23 (Courtesy of Food Machinery Corp., San Jose, Calif., U.S.A.)*

*Figure 25. Carton requiring no inner bag or overwrap. (Courtesy of Container Corp. of America, Chicago, Ill., U.S.A.)*


*Figure 26. This carton, with paperboard sides and metal ends, can be filled and closed like a metal can. (Courtesy of Quick Frozen Foods, New York, N.Y., U.S.A.)*

filling table, where the cartons are vibrated, they pass on for closing to a specially designed apparatus and are then carried to a wrapping machine like the one shown in Figure 22. These cartons can also be used in inserted moisture-vapor-proof bags, which are heat-sealed just before the cartons are closed.

Such packaging requires many operations. The wrapping operation may be dispensed with if a carton is used (with the necessary machinery) of the type shown in Figure 25. This carton is made of heavy, moisture-vapor-proof laminated board, making it possible to dispense with both inner bag and overwrap. The laminate can be heat-sealed.

It is possible to increase packing speed still further by applying to frozen foods the can-closing principles used for sterilized canned foods. Filling and closing can be stepped up to 150 to 160 cartons per minute. Figure 26 shows the carton used to make this possible. It consists of a heavy wax-treated fiberboard body with metal ends attached. Three large factories in the United States are producing these cartons which are generally called composite fiberboard cans or Canco containers.

## METAL CONTAINERS

Metal containers have the advantage that they reduce freezing time, but, in spite of their good protective qualities, cylindrical metal cans are not generally adopted for frozen foods. They utilize storage space less effectively than brick-shaped containers which is economically im-

portant because space in cold storage is more expensive than space in most other types of storage. Furthermore, contact freezers require containers of which the two largest faces are flat and parallel.


*Figure 27. Rectangular aluminum foil container.*

The brick-shape container is also preferred for quite another reason: A frozen product packed in an ordinary can of inflexible tin sheet may inadvertently be taken by the customer for a can of heat-sterilized food and allowed to stand thawed out for some time at room temperature. The consequent depreciation of quality may easily bring that brand into ill repute with the public. This can be avoided by using distinctive shapes and labels.

An interesting development in metal containers is that shown in Figure 27—a single layer of heavy aluminum foil which is folded into the shape of a box. The seams are tightened with a water-vapor-proof thermoplastic. The manufacturers claim that it reduces freezing time by one-third to one-half. Its glossy appearance gives it sales appeal, another important requirement in packaging. The desire for a glossy surface with more sales appeal often leads to use of the cold-waxing method of impregnating paperboard in preference to the more penetrating hot-waxing method.

## WHOLESALE CONTAINERS

Large containers are used especially for products such as berries, fruit pulp, and eggs, which are to undergo further processing after being thawed out. Quick freezing of such products is not absolutely necessary and surface dehydration does not impair them to any essential degree. Parchment or wax-paper lined fir barrels with a capacity of 110 or 190 liters are widely used, as well as kegs of 19 or 38 liter-capacity.

Figure 28 shows frozen-pack cans of 14 kg. and 19 liters (30 lb. or 5 gal.). These cans have excellent water-vapor-proofness, great mechanical strength and the square one has excellent stacking qualities.

## SHIPPING CONTAINERS

The prime function of shipping containers is to protect the smaller units packed in them. The foodstuffs are protected by the packaging materials of the smaller units. To save the smaller packages within from damage the shipping container must have the necessary mechanical strength.

*Figure 28. Large tin cans used for wholesale packs of fruit and eggs.*

Fiberboard cases are most generally used as shipping containers for frozen food. Solid, heavy fiberboard has proved stronger than the corrugated kind, the insulating qualities of which are unnecessary in modern refrigerated transport. Shipping cases must be so designed that their contents lie compactly, and the adhesive of the taping must be capable of withstanding long periods of cold. A tape consisting of asphalt laminated kraft paper has given particularly good results. Since many small packages, despite all safeguards, liberate a certain amount of water-vapor during long storage at low temperature, all closing parts and potential leakage spots such as edges and corners should be sealed with such tapes. If the packages within the shipping case are not sufficiently water-vapor-tight, and ice crystals form on the inner faces of the shipping case, the case must be enlarged, or better still reinforced. Ice crystal formations, if they do not break the case, make it bulge and create stacking troubles.

## TESTING SHIPPING CONTAINERS

Truly reliable information on the mechanical strength of such containers can only be obtained from a large number of test shipments during which the material's power of resistance can be observed under the practical conditions for which it was designed. But this often calls for an undue amount of time and work. Apparatus for simplified tests is often used in order to estimate the qualities of shipping containers. These tests are generally known, and only the most important are mentioned here.

Conditions in actual practice are best simulated by the drum- and drop-testers. By tumbling the fully packed shipping container in a drum with various internal projections, and by letting it fall in a definite way from a specified height, it is exposed to rough treatment capable of measurement.

Compression tests are important in ascertaining the resistance of the cases when piled. Finally, mention must be made of other important tests such as the Mullen, rigidity, and puncture tests. All testing of containers for frozen food should be carried out under temperature and humidity conditions which correspond exactly to the practical conditions under which the containers are to be used generally —18° C. and about 75 percent relative humidity.

Valuable information on testing methods can be obtained through the Technical Association of the Pulp and Paper Industry (TAPPI), New York, and the American Society for Testing Materials (ASTM), Philadelphia, Pennsylvania, U.S.A.

## STANDARDIZATION OF PACKAGE SIZES

Standardizing the size of packages is of great economic importance to European countries, where the production of frozen food has reached large proportions only in certain areas and where the import and export of frozen food and packaging materials should in the future become much more important. Carton sizes used throughout the world, present a rather confusing picture, but certain trends can be pointed out. Table 3 summarizes an elaborate survey in the United States periodical, *Quick Frozen Food* for May 1946. It shows current United States sizes of one-pound (454 g.) containers; 10, 12, or 14 ounces (284., 341, or 398 g.) of vegetables, according to the kind, are also packed in this size carton. Institutional packages are manufactured to contain from 2 to 2½ and 4 to 5 pounds (908 to 1,135 and 1,816 to 2,270 g.) of vegetables and 5 to 10 pounds of fish fillets. The dimensions used—length, width, and height—vary considerably among these larger cartons. The picture has not changed essentially since 1946. The most common size consumer package is 5¼ by 4 by 1¾ inches (123 by 102 by 44 mm.), the height varying from 3¾ to 6 inches (95 to 152 mm.).

An investigation undertaken in 1946 by the Eastern Frozen Food Association in the United States indicated that the frozen food packers were in favor of adopting as standard the following sizes:

A 12-ounce package—6 by 3½ by 1¾ in.; 36.75 cubic inches (approximately 602 $cm^3$) holding 12 ounces (340.5 g.) frozen vegetables (for example, peas), or 16 ounces (453.6 g.) of frozen fruit (for example, sliced strawberries); a 40-ounce package—10½ by 6 by 2 in.

TABLE 3.—DIMENSIONS OF 1-POUND (453.6 G.) CONTAINERS*

| Material to be packaged | Dimensions |
|---|---|
| | *Inches* |
| Fruit | 5 x 4 x 1½ |
| Fruit | 5⅛ x 4 x 1½ |
| Fruit | 5¼ x 4 x 1¼ |
| Vegetable [1] | 5¼ x 4 x 1¾ |
| Fruit [2] | 5¼ x 4 x 1¾ |
| Fruit | 5¼ x 4 x 1⅞ |
| Vegetable | 5¼ x 4⅛ x 1¾ |
| Fruit | 5¼ x 4⅛ x 1¾ |
| Vegetable | 5¼ x 4¼ x 1¾ |
| Fruit | 5¼ x 4¼ x 1¾ |
| Shrimp | 5¼ x 4¼ x 1¾ |
| Fruit | 5⅜ x 4 x 1¾ |
| Fruit | 5½ x 4 x 1⅞ |
| Fruit | 5½ x 4⅛ x 1¾ |
| Fruit | 6 x 4 x 1¾ |
| Shrimp | 6½ x 4 x 1¾ |

*SOURCE: Quick Frozen Food, 8:84, May 1946.
[1] Majority of vegetable 1-pound (453.6 g.) containers.
[2] Majority of fruit 1-pound (453.6 g.) containers.

126 cubic inches (approximately 2,065 $cm^3$); a 10-pound package—10½ by 12 by 4 in.; 504 cubic inches (approximately 8,260 $cm^3$). One shipping case measuring 12 by 10½ by 16 inches (about 300 by 270 by 400 mm.) could be used for any one of these three packages.

In Europe, current sizes vary even more than in the United States, but there is a tendency in the consumer sizes to prefer cartons with bases of 125 by 100 mm., 150 by 100 mm., and 200 by 75 mm. (5 by 4 in., 6 by 4 in., and 8 by 3 in.).

Norway and Denmark are very much interested in the standardization of carton sizes for frozen foods. With a view to international standardization under the IOS (International Organization of Standardization), the Norwegian Standardization Association has drafted specifications to govern the length of edge for standard carton sizes. Briefly these are as follows:

A basic shipment case is standardized with an inside minimum base of 250 by 200 mm., (10 by 8 in.) with a free choice of the third dimension of 200, 225, 250, and 300 mm. (8, 9, 10, and 12 in.). Dimensions of larger shipping cases are then fixed as multiples of the

dimensions of the minimum shipping case. For the small packages—consumer and institutional size—one dimension would be a simple fraction of 200, 225, 250 and 300 mm. In Denmark the work is based along the lines laid down by the Norwegian Standardization Association and centers about the selection of sizes suited to Danish and, if possible, Scandinavian requirements. Denmark has agreed for the time being to propose standardization in 14 different sizes: three heights on the base, 125 by 10 mm. (5 by 4 in.); three heights on the base, 150 by 100 mm. (6 by 4 in.); three heights on the base, 200 by 85 mm. (8 by 3 1/3 in.); four heights on the base, 250 by 125 mm. (10 by 5 in.); and one height on the base 250 by 200 mm. (10 by 8 in.), with six corresponding shipping cases.

## FUTURE TRENDS

The experience gained during World War II with new plastics, will no doubt be applied to the packaging of frozen foods. For instance there is the new "dip-coating." Products to be packed are dipped for a moment in the melted thermoplastic, which stiffens at room temperature. When the product is thawed out for use, the coating is simply stripped off.

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# 8. Judging Flavor, Color, and Texture of Food[1]

ORGANOLEPTIC testing of food means judging it by human senses—sight, smell, taste, and feeling.

The only thing that really matters in defining the quality of a particular food is the impression it makes on the human senses when it is eaten. The consumer impression of food is very complicated. The consumer gets a total impression, and he can hardly separate the whole into "part-impressions" of food. Generally it is impossible for another person, on the basis of a number of testings of single qualities, to form a true picture of the entire impression a particular food has made on a person who has judged it as a whole. A large and important part of the quality impression originates from the interaction of the single characteristics, and these simultaneously comprehended combinations may be quite decisive in reaching a judgment.

The form and color of a food can be precisely measured by finely constructed instruments. *But,* the attraction or repulsion of the combined color nuances, or the aesthetic impression of light and shadow, or the composition of the various shapes *cannot* be measured. Therefore, organoleptic testing is necessary. It must, as a matter of fact, form the basis of quality control of food.

Unfortunately organoleptic tests have a few very great disadvantages: They are subjective. The "measuring instruments" are very dissimilar, and, as a rule very uncertain.

There are two fundamentally different methods of organoleptic testing: difference testing and quality testing.

Difference testing is used to ascertain whether there is any difference between the characteristics of two or more products, but it does not measure differences in quality. Difference testing is well suited for experimental work: Results can be obtained with great certainty and

[1] Based on a paper presented by M. Kondrup.

they can be reproduced. Hence, they have value in the future.

The purpose of quality testing is to decide whether one product is better or poorer than another. These tests should be performed as far as possible only in connection with difference tests, either as succeeding independent tests, or, if desired, combined with difference testing. Quality tests are of greatest interest both to producer and consumer, but the great difficulty in obtaining even fairly accurate results lies in the divergent views as to what, in a given case, is better or poorer quality. The conception is subjective. What one person may consider an improvement another may consider a deterioration. Differing dietary habits of countries or regions make universal quality definitions impossible—and also make it impossible to arrive at results that can be reproduced. Publicity campaigns may gradually alter the attitude and taste of the consumers. Seasonal variations in food play a certain role—the poor ability of the consumers to remember particular quality characteristics in a particular food. For example, what should be the color of peas of optimum quality? Fresh frozen peas are almost always of a deeper green color—bluish green—than the same variety of peas in the fresh unfrozen state. Which is better? In the pea season many people think that frozen peas are "too green," but the same people, several months after the season when no fresh unfrozen peas are obtainable, find the deep green color of the frozen peas excellent, "just like" fresh unfrozen peas.

Two courses are open to ascertain which of two products is the better: The staff, a comparatively small testing panel at the factory, may decide what is good and what is bad, after laying down rules for changes in the different characteristics, in order that they may be called improvements. Or, market analysis may be used to find out what consumers consider as improvements. The first course is dangerous: It can by no means be taken for granted that the conception of a few persons about the quality of a product will be the same as that of the consuming public and will result in a product that is salable and competitive with other similar products. The latter course is expensive and troublesome: At least 400 to 500 persons must be included in a market analysis, as the lowest number required for reliable statistical conclusions to be drawn on the percentage of consumers preferring one product to another. The organization work connected with a market analysis may act as a deterrent.

## NUMBER OF TASTE TESTERS

The diagram in Figure 29 is taken from an article on statistical treatment of taste testing by the Swedish brewing engineer, Kjell Bengtsson, at the Svensk Bryggeritidsskrift in 1946. The curve shows

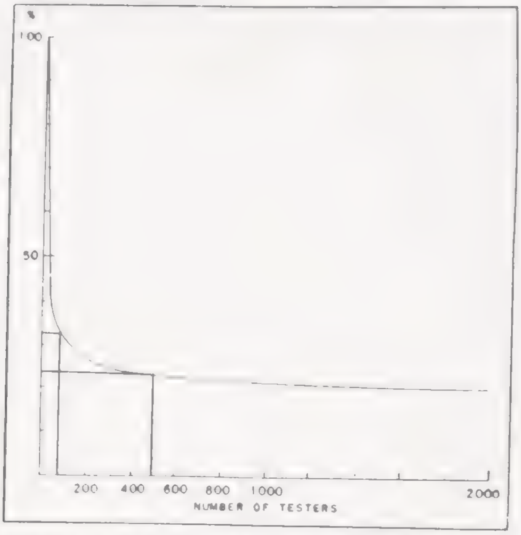



*Figure 29. Curve showing the percentage of the number of taste testers who must agree in order for results to be reliable.*

the percentage of different numbers of taste testers who must agree in order to rule out guesswork. Not much is gained by increasing the number of testers beyond 400 or 600, but with a low number of testers a far greater percentage of agreement is required to give the results the strength of proof.

Bengtsson states that if a food-packing plant which includes taste testing in its experimental work counts on 70 to 80 tasters, according to the curve corresponding to an agreement of from 30 to 35 percent—the result will be warrantable. Experience shows that if thoroughly trained tasters are employed who test products with which they are quite familiar, serviceable results in, for example, operating control may be obtained with only 10 to 20 tasters, partly because it is possible to sum up the results from different taste testings.

What is said here about the number of tasters applies both to difference and quality tasting, with the important proviso that quality tasting with a small number of tasters only gives reliable results if we can—or dare—assume that the opinion of this small number of persons really reflects the opinion of the consuming public.

One of the methods for obtaining more reliable results through organoleptic testing is to work it on a statistical basis.

The Scandinavian brewing industry in the last decade has greatly developed and improved the methods of tasting beer, with special stress on a statistical basis. The results arrived at can be transferred in many respects to the organoleptic tasting of many other products, including food preserved by cold.

The methods assume that organoleptic tests of small differences in products are likely to yield haphazard results. Therefore, to judge the results arrived at by a taste-testing panel it must be ascertained beforehand how large a part of the result may be guesswork. If the testing method and the number of testers are known, it is possible, by a few simple statistical calculations, to forecast how many of the participating testers will give an opinion in a definite direction in

order that there may be a certain probability fixed in advance of the result not being reached by mere guesswork.

Tests may be run as two-sample tests, multisample tests, and triangle tests. The latter is preferred. Triangle tests, used to ascertain quite small differences, are carried out in this manner: The testers are given three samples, two of which are absolutely alike. Before any different judging can be done, the tester must find out which of the three samples are alike. This method assures that the testers for psychological reasons are less inclined to guesswork. It also assures that the percentage of testers who will give an opinion in one definite direction is, for statistical reasons, lower than by the two other testing methods, and hence that the result has the strengh of proof.

## STATISTICAL ANALYSES OF RESULTS

The Swiss Bernoulli, about the year 1700, ascertained that the haphazard distribution in the cases which are of interest here takes place in accordance with the binomial theorem:

$$
\begin{aligned}
(p + q)^n = p^n & \\
& + n.p^{n-1} \cdot q^1 \\
& + \frac{n(n-1)}{1 \cdot 2} \cdot p^{n-2} \cdot q^2 \\
& + \frac{n(n-1)\,(n-2)}{1 \cdot 2 \cdot 3} \cdot p^{n-3} \cdot q^3 \\
& + \\
& + \frac{n}{1} \cdot p^1 \cdot q^{n-1} \\
& + q^n
\end{aligned}
$$

In this formula $p$ and $q$ denote the distribution of the votes given as mere guesswork. The values of $p$ and $q$ in figures depend upon the testing method chosen. In the two-sample test, where the tester is to decide whether one out of two samples differs from the other in a definite direction, 50 percent of the testers will by mere chance express themselves in favor of one sample, and 50 percent in favor of the other. In this case $p = 1/2$ and $q = 1/2$.

Multisample tests are treated like two-sample tests, the individual samples being compared 2 and 2. In triangle tests, where difference testing is necessary in the first place, and then, if desired, quality testing, one-third of the testers will by mere chance select the sample which *is* actually different from the others, and two-thirds of the testers will be mistaken, resulting in $p = 1/3$ and $q = 2/3$. Of the one-third who have selected the correct samples, half, or one sixth

TABLE 4.—NUMBER OF TESTERS REQUIRED IN A TESTING PANEL[1]

| Number of testers | Two-sample test * | ** | *** | Triangle tests: Difference test * | ** | *** | Quality test * | ** | *** | Number of testers |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | — | — | — | — | — | — | — | — | — | 1 |
| 2 | — | — | — | — | — | — | — | — | — | 2 |
| 3 | — | — | — | 3 | — | — | 3 | 3 | — | 3 |
| 4 | — | — | — | 4 | — | — | 3 | 4 | — | 4 |
| 5 | — | — | — | 4 | 5 | — | 4 | 4 | 5 | 5 |
| 6 | 6 | — | — | 5 | 6 | — | 4 | 5 | 6 | 6 |
| 7 | 7 | — | — | 5 | 6 | 7 | 4 | 5 | 6 | 7 |
| 8 | 8 | 8 | — | 6 | 7 | 8 | 5 | 5 | 6 | 8 |
| 9 | 8 | 9 | — | 6 | 7 | 8 | 5 | 6 | 7 | 9 |
| 10 | 9 | 10 | — | 7 | 8 | 9 | 5 | 6 | 7 | 10 |
| 11 | 10 | 11 | 11 | 7 | 8 | 10 | 5 | 6 | 8 | 11 |
| 12 | 10 | 11 | 12 | 8 | 9 | 10 | 6 | 7 | 8 | 12 |
| 13 | 11 | 12 | 13 | 8 | 9 | 11 | 6 | 7 | 8 | 13 |
| 14 | 12 | 13 | 14 | 9 | 10 | 11 | 6 | 7 | 9 | 14 |
| 15 | 12 | 13 | 14 | 9 | 10 | 12 | 7 | 8 | 9 | 15 |
| 16 | 13 | 14 | 15 | 9 | 11 | 12 | 7 | 8 | 9 | 16 |
| 17 | 13 | 15 | 16 | 10 | 11 | 13 | 7 | 8 | 10 | 17 |
| 18 | 14 | 15 | 17 | 10 | 12 | 13 | 7 | 9 | 10 | 18 |
| 19 | 15 | 16 | 17 | 11 | 12 | 14 | 8 | 9 | 10 | 19 |
| 20 | 15 | 17 | 18 | 11 | 13 | 14 | 8 | 9 | 11 | 20 |
| 21 | 16 | 17 | 19 | 12 | 13 | 15 | 8 | 9 | 11 | 21 |
| 22 | 17 | 18 | 19 | 12 | 14 | 15 | 8 | 10 | 11 | 22 |
| 23 | 17 | 19 | 20 | 12 | 14 | 16 | 9 | 10 | 12 | 23 |
| 24 | 18 | 19 | 21 | 13 | 15 | 16 | 9 | 10 | 12 | 24 |
| 25 | 18 | 20 | 21 | 13 | 15 | 17 | 9 | 10 | 12 | 25 |
| 26 | 19 | 20 | 22 | 14 | 15 | 17 | 9 | 11 | 12 | 26 |
| 27 | 20 | 21 | 23 | 14 | 16 | 18 | 10 | 11 | 13 | 27 |
| 28 | 20 | 22 | 23 | 15 | 16 | 18 | 10 | 11 | 13 | 28 |
| 29 | 21 | 22 | 24 | 15 | 17 | 19 | 10 | 11 | 13 | 29 |
| 30 | 21 | 23 | 25 | 15 | 17 | 19 | 10 | 12 | 13 | 30 |

[1] SOURCE: Kjell Bengtsson.

* Number of testers whose opinions reflect probability of error is below 5%.

** Reflects probability of error is less than 1%.

*** Reflects probability of error is less than 0.1%.

of all the testers, will by mere guesswork favor the sample of which there is only one and the other half will favor of the other samples. When the binomial theorem is used to find out whether the number of the participating testers who express themselves in favor of the single sample is sufficiently large in proportion to the total number of testers to give the result of the strength of proof, it is necessary in the binomial theorem to insert $p = 1/6$ and $q = 5/6$.

Further computations are more complicated, but the results of the computation may be inserted as in Table 4, which is an extract of a table prepared by Kjell Bengtsson.

This technique may, in a somewhat modified form, be applied to the testing of foods. The Danish Refrigeration Research Laboratory is using these methods to determine the suitability for freezing of different varieties of Danish berries and vegetables.

Many others besides the Scandinavians mentioned have done research on this subject. A reference list is given at the end of the chapter.

Organoleptic testings may also be improved in other ways. It is of the greatest importance to be able to select smaller panels of special testers, since it is very seldom possible to work with large testing panels. Not all persons are equally qualified for organoleptic testing. Great selectivity is required both toward small differences and small absolute values. Some persons are "taste blind," particularly in regard to bitter tastes. Age and training of the tester play some part, in addition to a good organoleptic memory, an ability which may exist in people of inferior organoleptic selectivity. Memory may be of great importance in certain tests, especially single-sample tests. Smokers may be excellent taste testers; there is so great a difference in peoples' tasting capacity that the difference between the capacity of smokers and nonsmokers is of subordinate importance.

## SELECTION OF TASTE PANELS

The selection of testers should be made on a statistical basis. Some investigators have been trying to determine the threshold values of human organoleptic perception, that is the smallest concentrations that can be tasted of the four primary components into which all tastes usually are divided: sour, sweet, salt, and bitter. It is possible to select special testers on the basis of their threshold values.

However, the experience of the Technological Laboratory of the Danish Department of Fisheries and of the Danish Refrigeration

*Figure 30. Taste-testing frozen food in one-man room.*

Research Laboratory has shown that, in spite of the large amount of work involved in this method, it does not ensure that the people chosen are especially capable of testing the kind of food they have to test. It is much better to find reliable testers by statistical methods, especially the triangle test. This would involve the use of foodstuffs the testers have to test during their daily work and with which they have had some previous experience. A thorough selection of experts may take a long time, but it pays in the long run. A small panel of first-class testers can give warrantable results. The warranty can be increased considerably by having the panel test the same samples several times. Thus, the selection of difference testers is only a problem of thoroughness and patience, but the selection of quality testers can cause great difficulties: The small panels must be so composed that they express the average opinion of consumers.

## TASTE-TESTING TECHNIQUE

The reliability of organoleptic testing can be increased by improving the technique itself. The conditions under which the tester works must be the best and most congenial possible. Noise, extraneous smells, loud colors, or having to stand disturbs and tires the tester and distracts his attention. He must concentrate completely on the task and must not be disturbed. Particular care should be
testers can cause great difficulties. The small panels must be so com-
denoting relish or disgust, statements by persons who may be sup-

Material ______ 19 a.m. p.m.

FOOD QUALITY ASSESSMENT CARD

Judge ______ Investigator ______

| Sample | Colour Typical | Colour Off | Texture | | Odour Typical | Odour Off | Flavour Typical | Flavour Off | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Standard | | | | | | | | | |
| 1 | | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | | | | | | | | |
| 4 | | | | | | | | | |
| Total: | | | | | | | | | |

(See over)

*Figure 31. Score card used in recording results of food testing.*

SCORING SCALES TO BE USED

Scale 1.- For assessing typical colour, texture, odour and flavour.

+5
+4 Excess
+3
+2
+1

0 Ideal

-1
-2 Deficiency
-3
-4
-5

Scale 2.- For assessing off colour, odour and flavour.

0 Ideal
1
2
3
4
5 Excess

Scoring scales for other characteristics to be in accordance with specific instructions from the standing committee on taste panels.

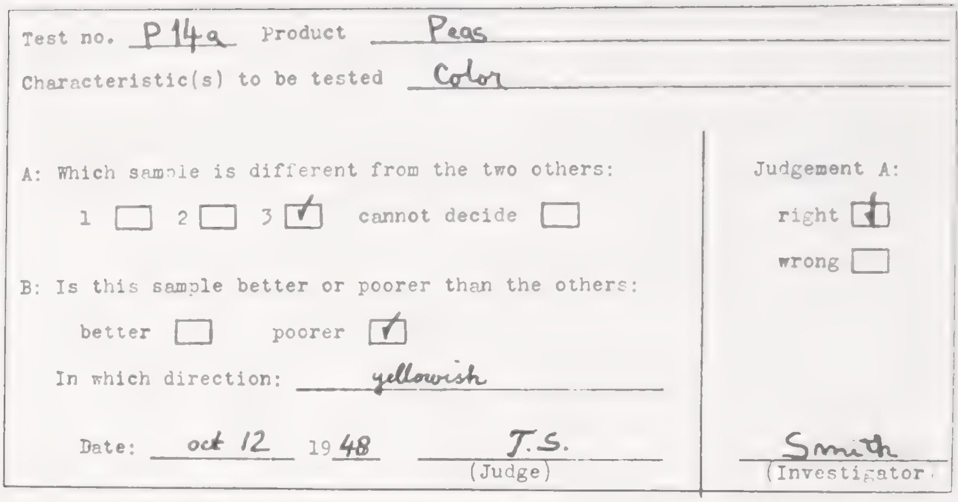
*Figure 32. Scoring scales used in judging frozen foods.*

posed to be in authority—all this may influence the tester's personal opinion and damage the reliability of the results.

Small one-man rooms are often fitted up in large laboratories in which testing can be done in peace and quiet (Figure 30). Here there is nothing to distract the tester. The samples are handed to him through the opening in the walls. The samples are nameless, having only code numbers. The leader, who does not take part in the testing, briefs the testers just before the test, giving them instructions about points to which their attention should be directed. The samples served, one of which is standard, are of the same temperature. Bowls and spoons are tasteless, odorless, and of a neutral color. The tester does not swallow samples, but after tasting a sample he deposits it in a filter paper such as those shown in the two beakers in the background.

## SCORE CARDS

The score card shown in Figure 31 is used to record the results. These cards, filled in and signed, are collected and handed to the leader before the testers are permitted to speak to one another about the testing. This card is intended for quality testing by experts, experienced in testing the foods served, and who know beforehand what is good quality and what is bad. Scale 1 of the card (Figure 32)


Test no. P 14a Product Peas

Characteristic(s) to be tested Color

A: Which sample is different from the two others:

1 ☐ 2 ☐ 3 ☑ cannot decide ☐

B: Is this sample better or poorer than the others:

better ☐ poorer ☑

In which direction: yellowish

Date: oct 12 19 48 T.S. (Judge)

Judgement A:

right ☑

wrong ☐

Smith (Investigator)

*Figure 33. Typical record card used for a "triangular" taste test.*

fluctuates from minus 5, "totally lacking," to a plus 5, "totally unfit." Particular values in points may, if necessary, be provided with standardized descriptions.

If a triangular test were to be undertaken, a form such as the one in Figure 33 is needed. The judge checks the squares on the left hand side of the form, the leader checks the right hand side.

Tests done by trained persons at the Technological Laboratory of the Danish Ministry of Fisheries and at the Danish Refrigeration Research Laboratory rate the characteristics of color, odor, taste, and texture according to a scale, on which 1 point is given for "bad" and up to 5 points for "excellent," the standard deviation for testings on

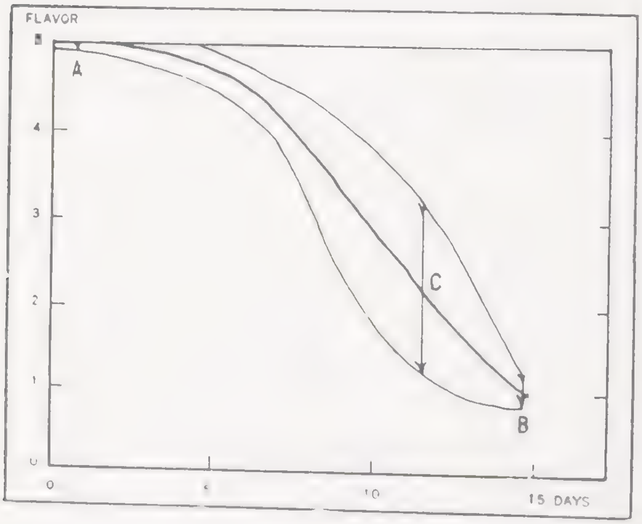



*Figure 34. Decline in flavor of cod fillets during 15-day storage at +1 (*

the middle part of the scale is ruling between $\pm\frac{1}{2}$ and $\pm 1$ point, smallest for color and highest for odor.

Figure 34 shows the decline in quality for the taste of cod fillet from the time of death until putrefaction sets in after about 15 days. The middle, boldest curve denotes the average testings in comparison with the time of storing at $+1°$ C. The vertical distance from the bold curve to the thin curves denotes the standard deviation of the testing panel at various points. It will be seen that the panel tests most effectively at A and B (5 points = excellent, and 1 point = bad) less effectively around C (2 points = poor).

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# 9. Plant Sanitation[1]

PERISHABLE FOODS are excellent media for the growth of micro-organisms, especially bacteria and molds. A study of the micro-organisms of beef and pork indicated 239 different strains of nonspore-bearing bacteria, eight strains of aerobic spore-bearing bacteria, and 59 strains of spore-bearing anaerobes. In addition many different molds were found. The flora of fish consist principally of achromobacter, micrococci, flavobacteria, pseudomonas, and bacilli.

The optimum temperature for the growth of many micro-organisms at about 37° C. As the temperature is reduced, the growth of micro-organisms and the consequent spoilage of foods is less rapid. As a rule, the lower the temperature the less rapid the growth of spoilage organisms, but most of these bacteria, molds, and also yeasts are capable of growth and may cause food spoilage even at +1° C.

Freezing of foods kills some of the micro-organisms, but only in fruit juices does it destroy a large proportion of the bacteria. However, when the temperature of foods is reduced to about −10° C., the growth of micro-organisms becomes so slow that it does not spoil them. However, if the temperature of the frozen foods rises above 0° C., micro-organisms again begin to multiply and soon cause spoilage.

Since refrigeration or even freezing does not sterilize foods, a high degree of sanitation is necessary in order to prevent contamination of foods by pathogenic and food poisoning micro-organisms.

## GOVERNMENT SANITARY INSPECTION

In Denmark, for example, cold storage plants work principally for the export trade in meat, pork, eggs, and butter. The meat-packing industry is subject to government meat inspection, extending

[1]Based principally on a paper presented by Aage Jepsen.

to government inspection of sanitary conditions in cold storage plants. Every cold-storage plant has an inspecting veterinary officer and a lay inspector, both appointed by the Ministry of Agriculture. Inspectors must see to it that: (1) only fresh and sound products are admitted to the plant, (2) all meat products are properly inspected, (3) all goods are stored and handled in a sanitary manner, and (4) the whole plant is kept clean and sanitary. Specific rules are established for cleaning and disinfection of rooms and equipment.

To establish and maintain proper sanitary conditions in food plants of all types, certain fundamental needs must be met in the construction of buildings and equipment. The capacity of rooms and machinery must be designed to meet the maximum amount of work to be expected, for nobody can run an overcrowded plant in a dependable sanitary manner. Both the building and the equipment must meet certain sanitary standards so they can be maintained in a clean and sanitary condition. Floors and walls should be covered with waterproof material, so that they can be washed or hosed down. Corrosion-resistant metal should be used in preference to wooden material whenever possible. Water supply and drainage should be ample and safe. Washing facilities should be sufficient, and the rooms should be well lighted and ventilated. Practical information on details of sanitary building construction can be found in several information sheets issued by the Federal Meat Inspection Service of the U.S. Department of Agriculture, Washington, D.C.

## BACTERIOLOGICAL EXAMINATIONS

Assuming that a plant meets the construction requirements, there remains the question of sanitation methods for daily use. There are many ways of controlling the microbe population in food preparation and storage rooms, but no standard method is satisfactory for all purposes. A careful analysis should be made of all sanitary problems which present themselves in a particular plant and its particular type of work. Bacteriological examinations are very useful in tracing possible sources of contamination. Food products and processing equipment should be tested at each stage in processing. Methods of examining various foods for microbes have been extensively studied and described by several United States authors, as have methods for examining processing equipment, often by swabbing with sterile cotton. Certain methods already have been proposed as tentative standard methods. In the Royal Veterinary and Agricultural College Laboratory some work of this type has been done, especially in milk- and meat-processing plants. Total bacterial counts, tests for coliform bacilli, and sometimes spore-bearing anaerobes have proved

useful in analyzing sanitation problems. Evaluation of bacteriological results and detailed records of the particular processing phases indicate what sanitation procedure should be adopted.

## SANITATION OF EQUIPMENT

It is difficult, if not impossible, to set up specifications for each specific situation, but some general rules can be given:

If air-borne contamination is a main factor, ultraviolet light, ozone, or glycol sprays may be adequate.

In most situations, contamination by contact with utensils and equipment is by far the most important. The best method of sanitation involves cleaning and disinfection by heat or by chemical disinfectants.

Good cleaning must precede every disinfection in order to obtain reliable results. This is especially true of chemical sterilization. But dirty utensils are always objectionable, whether sterile or not. Cleaning requires plenty of cold and hot water and plenty of scrubbing and brushing.

Proper use of effective detergents may greatly improve and facilitate cleaning, but the amount and kind of work involved is a most important factor. In Denmark, soaps, caustic soda, sodium hydroxide, polyphosphates, and silicates are the only detergents available for common use, and they remain rather scarce.

Good cleaning in many cases is about 90 percent of the sanitation process.

After cleaning comes sterilization. Whenever possible, sterilization by heat should be used, because heat has greater penetration than chemical agents. But, in using heat, it is necessary to make sure that the surface to be sterilized actually reaches a proper temperature and remains there for a sufficient length of time. That is not always accomplished by low-pressure steam on open surfaces. Closed containers and pipelines can be submitted to pressure steam and thus safely sterilized. Some years ago it was found that certain gelatin products became badly contaminated, chiefly with spore-bearing anaerobes, in low-temperature vacuum evaporators. These sporebearers were not destroyed by chemical disinfection, but the trouble was overcome when the evaporators and connecting pipelines were so equipped that they could be subjected to steam under pressure.

Chlorine compounds are still most widely used for chemical disinfection of food plants in Denmark. None of the quaternary ammonium compounds developed in recent years has become available for common use. Official regulations on sanitation, for instance in the dairy industry and in the meat-packing industry, recommend

calcium or sodium hypochlorites. The chlorine compounds are generally recognized as relatively cheap and effective germicides on clean surfaces. They are nontoxic in use dilutions and do an effective job of killing vegetative cells, but are said to be ineffective on spores.

In recent years some work has been done in Denmark which indicates that the effect of chlorine largely depends on the pH of the medium. The main factor in chlorine disinfection is whether conditions in the active solution allow the formation of hypochlorite ions. At high pH values chlorine solutions are stable but less effective. Lowering pH mobilizes the hypochlorite ions and increases the killing effect, but accelerates the breakdown of the compound and results in rapid inactivation of the germicide. This means that, at a lower pH, there is a strong but short effect from chlorine disinfectants. If enough hydrochloric acid is added to neutralize a calcium hypochlorite solution and to mobilize part of the hypochlorite, the solution is very active in killing tubercle bacilli, which are not easily killed by neutral or alkaline hypochlorite solutions. The same is true of chloramine solutions. Adjustment of the pH to about 6 is advisable, if chlorine compounds are to be used to destroy spore-bearers or other resistant micro-organisms; ordinary, less resistant micro-organisms can be satisfactorily overcome without that adjustment. Such an adjustment of the pH makes an unstable solution that can only be used immediately after it is prepared, while alkaline solutions of chlorine are comparatively stable.

Solutions of chlorine applied to surfaces soon lose their sterilizing effect, even at an alkaline pH. Like other oxidizing disinfectants, chlorine compounds have no residual killing effect, because the active ions lose their power of disinfection because of reduction. This is a great advantage in a way, because it prevents toxic effects and the development of off-flavors. But, a disinfectant would be more useful, if, besides being nontoxic and free from taste and odor, it would produce a more lasting effect. The quaternary ammonium compounds have many of these qualities. Their residual killing effect is shown by an experiment by Mallman and Churchill. They painted a wooden wall with solutions of hypochlorites and a quaternary ammonium compound. Two hours later the treated surfaces were sprayed with a culture of a micrococcus. The surface treated with the quaternary ammonium compound soon became sterile, whereas that treated with hypochlorite had lost its bactericidal properties. In another experiment, Mallman treated a smooth pine board heavily with a 10 percent solution of a quaternary ammonium compound. After 1, 3, and 14 days the board was sprayed with a micrococcus. Samples taken five minutes after exposure all proved sterile. This means that, on heavily impregnated wooden surfaces, contaminating bacteria are killed in five minutes even two weeks after

treatment. Table 5 shows results of surface treatment of a wall, heavily contaminated with molds and bacteria. The unpainted concrete surface population drops from 28,000,000 per 2-inch square to 380,000 by washing with trisodium phosphate. Rinsing with water reduces the count to 53,000, and swabbing with the disinfectant reduces the count to 100. Swabbing on the same wall with the disinfectant without previously cleaning, only reduces the count to 11,000,000. This clearly demonstrates the fact that, even when quaternary ammonium compounds are used, good cleaning must precede sanitization.

Sanitation of food plants usually is performed as a discontinuous process. In common practice, cleaning and sanitization of work rooms and equipment takes place only once a day, at the end of the day's work. Cold-storage rooms and freezers must be emptied and the cold turned off before washing with water and disinfectants can be started. Naturally, this can only be done at long intervals; in Denmark cold stores are subjected to government veterinary inspection usually twice a year, whereas receiving rooms must be cleaned once a day. When a freezer or a freezer storage room is to be cleaned, all stored goods, racks, trays, and other movable equipment are moved out. Then the room is heated by an electrical heater before washing and disinfection. In about three or four days the room can be used again.

The ideal method of applying chemical inhibitory or killing agents to chilled food storage rooms would be a concurrent and more or less continuous air treatment, that would destroy organisms in the air as well as on the surfaces. A number of such procedures have been

TABLE 5.—EFFECT OF TREATING SURFACES WITH DISINFECTANTS *

| Treatment | No. of bacteria per 2-in. square |
|---|---|
| Before treatment | |
| Painted surface | 260,000 |
| Unpainted concrete surface | 28,000,000 |
| Washed with trisodium phosphate solution | |
| Painted surface | 250,000 |
| Unpainted surface | 380,000 |
| Rinsed with tap water | |
| Painted surface | 26,000 |
| Unpainted surface | 53,000 |
| Swabbed with 1:1000 cationic disinfectant | |
| Painted surface | 0 |
| Unpainted surface | 100 |
| Treated without cleaning | 11,000,000 |

* SOURCE: The control of microörganisms in food storage. Mallmann, W. L., and Churchill, E. S. *Refrig. Engineer.* (New York, N.Y.) 51:523-28; 552-53. 1946.

applied—ultraviolet lamps, ozone generators, carbon dioxide, and glycol sprays. Each of these may prove useful within certain limits, for special objects, but not for all-round sanitation. Nothing that is acceptable in food rooms has been found so far that will replace ordinary cleaning and surface disinfection. A glycol spray is rather effective against vegetative cells, but the spores of molds and bacteria are unaffected. Quaternary ammonium air sprays in a 10 percent solution are fairly effective. Clean surfaces on the wall in a refrigerator were sprayed with 24-hour-old cultures, and immediately afterwards a 10 percent quarternary ammonium solution was sprayed into the air of the refrigerator. Later the contaminated surfaces were found to be nearly sterile.

Sanitation in food plants, as already mentioned, is usually performed as a discontinuous procedure once a day. In several types of work, however, recontamination occurs so rapidly that very little has been achieved by this method to protect foods from microorganisms. The answer is to adopt some method for continuous sanitizing of processing equipment. In some food-processing plants, for instance, elevators and conveyor belts carrying foods are kept permanently clean and sanitary by passing them through tanks or sprays of disinfectants.

## IN-PLANT CHLORINATION

A special method of continuous plant sanitization is "in-plant" chlorination, developed recently in the United States of America. In-plant chlorination means that chlorinated water is used continuously to sanitize food-processing equipment. This application depends on a special chlorinator that ensures a constant concentration of free available chlorine in the water supply of the plant. This should prove very useful in many food plants.

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# 10. Chilled and Frozen Foods

## CHILLED AND FROZEN DAIRY PRODUCTS

COOLING has been used from ancient times as a method of extending the storage life of dairy products. Originally only cold water and natural ice were used for cooling. When refrigerators appeared on the market, and as construction of this machinery was improved, artificial cooling became more and more common in the dairy and other food industries.

Refrigeration has made it possible to carry dairy products over great distances by trucks, by railways, and by ships. Furthermore, it has become possible to regulate the supply of dairy products so that the great seasonal fluctuations in production do not necessarily result in the same fluctuations in quantities offered for sale on the market.

### Cooling Milk on the Farm

The producer of milk knows that the keeping quality of milk is increased in the same degree as the milk is cooled. Many types of simple equipment have been manufactured to cool milk with water at the place of production, thus improving the quality of the product delivered to the dairies for further treatment. But, it is not always possible to get water in sufficient quantities and at a sufficiently low temperature. Refrigeration equipment for use on the farm has been produced that thoroughly cools the milk immediately after milking. It may, however, be very difficult and take a long time to induce Danish farmers to install mechanical refrigeration equipment such as is commonly used by the better dairy farms of the United States of America.

[1]Based on a paper presented by S. Nielsen.

### *Cooling in Dairy Plants*

Refrigeration is indispensable in a dairy plant. Fluid milk must be cooled immediately after pasturization to prevent the development of bacteria.

The refrigeration of whipping cream is important, not only for the same reason, but also to improve the whipping quality and to make the whipped cream stable. Even in normal times, when the dairies themselves established the fat content of the whipping cream, they always took care to ripen the cream for several hours at temperatures close to the freezing point in order to get the best possible product. In these days, when the fat content of the whipping cream must be below 10 percent, cooling plays a much greater role than before. It is usual to make several coolings interrupted by slight warmings in order to get the right crystalline formation in the butterfat and increase the viscosity of the cream.

### *Refrigerated Transport of Milk*

Since 1946 there has been, for example, a considerable export from Denmark of fluid milk in bottles, especially to the U. S. Army in Germany. This export, has, from a small beginning, developed into a daily export of 60,000 liters of bottled whole milk.

Part of the milk is shipped as far as Vienna, a distance of about 960 kilometers. In order to transport milk this far without great deterioration in quality, it is absolutely necessary that the milk be cooled effectively from the place of production to the consumer.

Dairies are required to deliver the milk in bottles at a temperature not exceeding 8° C. If the temperature is higher, the milk is rejected. From various Danish dairies the milk is transported to Flensburg-Weiche by refrigerated trucks with two different systems of refrigeration:

1. Trucks with sanitary built-in automatic refrigeration worked by separate motors so they can function if the truck's motor breaks down. These refrigerators maintain the temperature of the milk from the dairies and, in special cases where long distance is involved, it is possible to reduce the temperature of the milk by 1° or 2° C. Accordingly, this system of refrigeration is preferred where great distances are involved.

2. Trucks in which the milk is cooled by crushed ice. To get full use of the ice, it must be crushed into small pieces, and then placed among the bottles, cooling the milk as it melts. This system is most effective over short distances because it cools the milk quickly. There is, of course, the risk that a careless driver may scoop the ice across the bottles and damage many of the caps.

Upon arrival at Flensburg-Weiche the milk is transferred from

the truck to a milk-train having ice-cooled cars, each of which has been filled with four tons of crushed ice, and is well cooled before loading begins. On the way through Germany the cars are re-iced in Bremen and, if necessary, in Frankfurt.

At the various unloading points in Germany the milk is picked up by refrigerated trucks which carry it to shops or canteens where it is again stored in refrigerators until used, or until the housewife buys it and takes it to her own refrigerator. Milk for Vienna is four days old before it reaches the consumer, but its temperature throughout transportation has been kept at 10° C. or below.

Not a single complaint of sour milk has been received. Even on the warmest days the milk has reached consumers in first-class condition. Laboratory tests made by United States laboratories in Germany show that the bacterial count is satisfactory and that *B. coli* is very rare.

This transport of milk — which at first was only an attempt — shows that it is possible to transport fresh milk over long distances if the milk is at all times well-cooled.

## Cooling Cream for Butter

The crystalline formation of butterfat for butter-making is of great importance to the body and texture of the butter.

In winter, efforts are made to product butter with large fat crystals; this provides soft and smearable butter even at a comparatively low temperature. The formation of larger fat crystals is encouraged if the cream is cooled down to 8° C. or lower immediately after pasteurization. When the cream is kept at this temperature for about two hours, many small fat crystals are formed. With these as starting points, large crystals are formed when the cream is slowly warmed to and kept at 18° to 20° C. This method of cooling the cream has been of great importance to the quality of Danish butter and has made its manufacture more economical.

In summer, smaller fat crystals are desirable in order to make firm butter. Immediately after pasteurization the cream is cooled down to the ripening temperature of 18° to 20° C. A few hours later it is cooled down to 15° C., while the cooling to a churning temperature of 8° to 10° C. is done immediately before churning.

## Cold Storage of Butter

Butter is manufactured in all Danish dairies, for example, from thoroughly ripened cream. Normally it has a salt content of about 1 percent. Butter of this type usually is not suitable for cold storing; it tends to become oily, with increasing acidity and salt content. The strong flavor with which the butter is manufactured causes a

reduction in its keeping quality; it should be eaten before it is three or four weeks old.

In 1943 a committee for the regulation of the market was established to stabilize the market and counteract price fluctuations. When the supply of butter was too great, this committee bought it up and kept it in cold storage for sale when the supply was scarce. During World War II the committee stored butter in order to get supplies for the home market during the winter months.

Most of the butter the Germans bought during the war was stored for six to nine months before it was eaten. Since the liberation, the British Ministry of Food has stored Danish butter up to four months before it was marketed. The change of conditions has caused the Danish dairy industry to take an increased interest in cold-storing butter, and during the last ten years several experiments have been carried out.

In 1936-38 the Danish Butter Testing Institute made some experiments on the keeping quality of Danish butter, which was stored for three months at —8° C. The results prove that the deterioration of the butter during storage is not due to microbiological development, but to its becoming oily. The depreciation in the score of stored butter compared with fresh butter was:

| | |
|---|---|
| For butter made in January-March | 0.6 |
| For butter made in May-July | 1.1 |
| For butter made in August-November | 1.5 |

Furthermore, it has been proved that unsalted butter keeps better than salted, and that variations in the pH value have no effect on its keeping quality.

A comparison of the butter from five dairies with equipment of stainless steel, aluminum, and well-tinned copper and iron and that of five others with equipment of copper and iron with worn tinning clearly showed that the presence of iron and copper damages butter during storage.

On the initiative of the Danish refrigeration industry, a new series of experiments were started in co-operation with the State Butter Testing Institute, the Experimental Dairy, and the Dairy Laboratory which indicated that the use of especially low temperatures does not prevent butter from becoming oily, but that butter stored at the lowest temperatures had the best average score. Further, it was found that if the butter is stored for six months instead of three, the quality is considerably depreciated. The dominant fault in cold-stored butter is an oily taste.

Danish butter made from ripened cream can be cold-stored without becoming excessively oily because it contains less than 1 percent of salt. Butter with a higher salt content becomes very oily during cold storage.

The Danish dairy industry faces difficulties when Great Britain demands a salt content of more than 1 percent, and at the same time keeps Danish butter in cold storage for several months.

Recently a special Finnish salt was tried, which contains certain chemicals that neutralize the acid in the serum of the butter. In this experiment 720 butter samples were tested and analyzed, of which one-third contained ordinary salt, one-third contained the special salt, and one-third were unsalted. Briefly, these experiments indicated that part of the special-salted butter lost some of its freshness during manufacture or had an aftertaste which, however, was usually not very noticeable. After storage it was of a considerably better quality than the butter salted with ordinary salt. The neutralization had counteracted the oily fault, but in many cases minor faults were noted. The results were not entirely satisfactory, perhaps partly because the salt content was too low, and partly because the dairies did not have enough experience with the special salt. The unsalted butter and the special-salted butter were about identical in keeping quality, and both were better than normal salted butter. Other methods for the prevention of oily taste are being studied.

A storage temperature for butter of —18° to —20° C. gives better results than —10° C. or higher, and that unsalted and strongly salted butter keeps better at —6° to —7° C. than slightly salted butter (0.2 to 0.5 percent of salt). Experiments have been done with storage of thick, unripened cream which, after eight months' storage, was manufactured into butter. Butter made from the stored, unripened cream was satisfactory, but butter, made from stored cream ripened before churning, quickly became oily in storage.

It has been found that no essential advantage is gained by using temperatures below —10° or —12° C., while —6° to —8° C. is too high. The difference may be that water and buttermilk ingredients freeze very slowly and incompletely in salted butter at —6° C., but freeze quickly at —10° C., considerably restraining the enzymatic and chemical processes.

The quality of butter, packed in lightproof and airtight material, after storing for two, four, six, and eight months was better than the control butter in a 40-kilogram package wrapped in parchment and packed in wooden boxes.

The manufacture of cold-storage butter from sweet cream and salting the butter to avoid mold growth is recommended. Cold-stored butter is firmer after thawing than butter which had not been frozen.

The conclusion to be drawn from these experiments is that butter which must be stored for several months ought to be cooled down immediately after it is produced. Cooling below its freezing point, which with 1 percent salt is about —4° C., is advisable for soft butter.

### *Cheese Storage*

While it is advantageous to keep butter at the lowest temperature possible from the moment it leaves the churn until it is delivered to the customer, the conditions are quite different for cheese. From the time when a cheese is molded and pressed, it must be kept at the right temperature, and in the right conditions for ripening. Individual types of cheeses require different conditions. In the brine, which is used for salting hard cheese, the temperature must be kept constant. The cheese increases the temperature of the brine, so it is necessary to have artificial cooling; water-cooling usually is not sufficient. In rooms where cheeses are fermented and ripened, the temperature must be completely under control. Especially in the warm summer months, this demands a rather considerable cooling capacity.

If cheese could always be sold to consumers when it is ripe, the problem would be simple. This is seldom possible because the production of cheese is subject to great seasonal fluctuation, while consumption is rather constant the year round. To arrest the ripening process it is necessary at a certain time to counteract it by cooling. Ripening cannot be stopped completely; it can only be checked.

A storage temperature of about 0° C. is generally preferred for fully ripened cheese. This temperature is preferred because the moisture freezes in the cheese if it is exposed to lower temperatures. There is some disagreement about the freezing point of cheese. In his *Fundamentals of Dairy Science*, L. A. Rogers gives the following freezing points for several varieties of cheese:

| *Variety of cheese* | *Freezing point* |
|---|---|
| Cottage | —1.2° C. |
| American (processed) | —6.9° C. |
| Swiss (domestic) | —10.0° C. |
| Cheddar | —12.9° C. |
| Roquefort | —16.3° C. |

Great variations in the freezing point of cheeses of the same type are explained by Rogers in the following way. The moisture content of a cheese does not vary markedly with ripening. Since the freezing point decreases with curing, it seems evident that water must be removed from its role as solvent, probably by combination with the proteins of the cheese. This has not yet been investigated, but it does mean that a statement of the freezing point of a cheese without stating its age is of no great value. The freezing points of 15 different Cheddar cheeses ranges from —4.3° to —14.3° C.

Storage of cheese at —10° C. results in shattering the body of the cheese, owing to loosening the original curd particles from their cohesion. This effect is not so marked with cheese matured at 7° to

10° C. for 160 days before being transferred to freezing temperatures. Frozen cheese also has a soapy, insipid, and somewhat tallowy flavor. Holding the cheese at 7° to 10° C. for two months after removal from storage at —10° C. improves both the texture and the flavor, but does not completely remove the objectionable features.

Cheddar cheese was cut into small portions (9 by 9 by 2.5 cm.), which were wrapped in tin or aluminum foil, and were cooled from 4° to —16° C. in 60 minutes by a blast of cold air at —25° C. The quality of the "fast frozen" cheese was not injured and could be kept in frozen storage for several weeks without visible deterioration. The "fast-freezing" process does not shatter the cheese structure as slow freezing does.

In a study on low-temperature storage of 3,500 samples of Herregaard, Svecia, and Gouda cheeses held at 2° C., compared with the usual storage temperature of 13° to 14° C., it was found that the age of the cheese when stored is of considerable importance. If too young cheese, for example two-month-old Herregaard, is placed in cold storage after six-months' storage it scarcely reaches optimum quality, while the low-temperature storage of somewhat older cheese raises the grade above the maximum for normal temperature storage. However, Svecia cheese stored at the age of six weeks is the best quality for low-temperature storage. Protein decomposition is retarded by low-temperature storage, but nothing in this investigation indicates that the decomposition proceeds in any abnormal manner during low-temperature storage. Cheeses stored at a low temperature were not criticized more or in a different way than those stored at normal temperature. Low-temperature storage seems to prevent the formation of volatile acids, without having any influence on the grade, and raising the storage temperature does not start the process over again.

The age of the cheese when placed in storage should be decided according to the intended length of storage period. The examples given here concern six-months' storage. However, provided the cheese is neither too young nor too old, only a fairly rough estimate is required; the most suitable age for six-months' storage is between two and three months. When the cheese is stored at such an age as to be fully ripened on removal, it follows naturally that it becomes overripe if kept for any length of time at normal temperatures.

In these tests the cheeses were piled in various ways in order to determine the influence this had on the rind and the paraffin coating of the cheese, and to learn how this affected the capacity of the storage. By removing every other shelf and placing the cheeses on their edges, the capacity of the store was increased by 67 percent. The cheeses had to be turned often, but cracks still appeared on the rinds.

These experiments show that cheese which has reached a certain age can be stored with advantage for several months at temperatures of about 0° C. The proper age of the cheese to be cold stored should be decided, *firstly,* according to the temperature of the cold storage, *secondly,* how long it will be there, and *thirdly,* how long it will be from the time the cheese is removed from cold storage until it is eaten.

The usual storage temperature for cheese is 0° C., but it should be possible to use considerably lower temperatures. The temperature must not be so low that the moisture of the cheese freezes and damages the consistency of the cheese. The lower the temperature employed, the more decomposition is retarded. The point is, then, whether the value of this retardation is equal to the expense of the increased cooling.

Instead of removing every other shelf in the cold storage, a better method is to remove all the shelves and store the cheese in boxes ready for shipping. This method permits the turning of the cheeses, if necessary, by turning the boxes, and it increases the capacity of the storeroom by 200 percent.

## CHILLED AND FROZEN LEAN FISH[2]

### Chilling

Fish is chilled to keep it as fresh as possible without freezing. Changes in the quality of freshly caught fish are chiefly caused by autolysis and growth of bacteria. One of the first changes depends upon the conversion of glycogen to lactic acid; the fish becomes stiff and enters the condition called rigor mortis. Fish caught with line and in nets normally remain in this condition until they are nearly stale by the action of bacteria, the chief reason for spoilage. In fish caught by trawlers, rigor may not last nearly as long.

The changes in fish which eventually result in spoilage may be judged by appearance, firmness, and odor. As spoilage advances, the eyes become dull, the gills brownish, the flesh soft, the fresh sea odor is lost, and a stale fishy odor replaces it. But these subjective judgments are uncertain. More exact and objective methods are desirable. Such methods are, for example, bacterial counts and the determination of volatile N-bases, as ammonia and trimethylamine. Bacterial counts are the most reliable, but the chemical methods give results faster and with much less work. Numerous tests by Canadian, British, and other workers have shown that the content of trimethylamine gives an especially good measure of the freshness

[2]Based on a paper presented by O. Notevarp.

of many marine fishes such as cod, haddock, flounder, halibut, and herring.

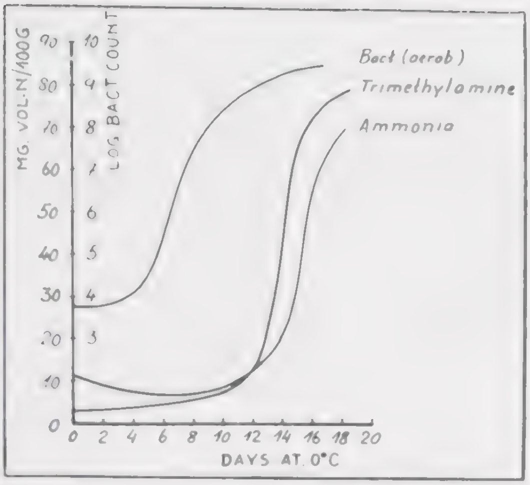



*Figure 35. Mean values for bacterial counts and volatile nitrogen in cod stored at 0° C.*

Figure 35 shows mean values for bacterial counts, ammonia-N and trimethylamine-N, in Norwegian cod stored at 0° C. Growth of bacteria is very rapid from the fifth or sixth day, and the trimethylamine-content increases all the time, with a very sharp increase from the tenth to the twelfth day. Ammonia-N decreases the first four to five days and is not as good a criterion of freshness as trimethylamine-N. Cod of good quality should not contain more than about 10 mg. trimethylamine-N per 100 g. The curves indicate that the rate of spoilage increases very fast after a certain storage time. The falling-off after about 12 days of the curve for bacterial counts is caused by increased death rate of bacteria. The rate of formation of volatile bases increases until the fish is putrid.

The rate of spoilage depends very much on temperature. Figure 36 demonstrates how fast fish spoil at different temperatures. The marks for quality are about proportional to the logarithm of the bacterial counts or to the content of trimethylamine. The effect of temperature is chiefly based on experiments, but has also been cal-

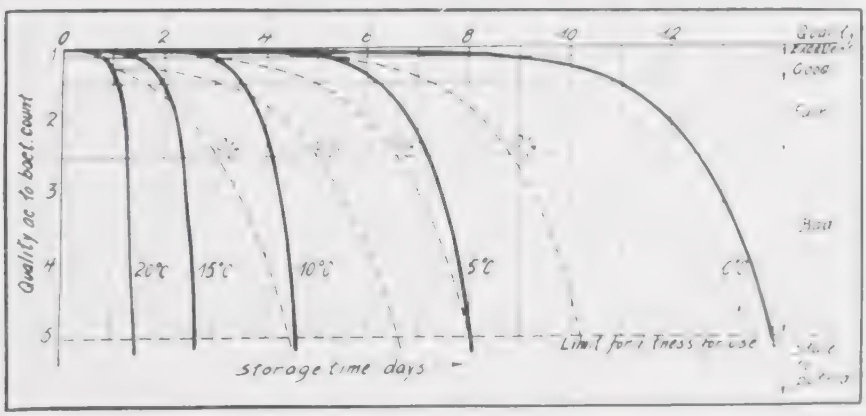



*Figure 36. Decrease in quality of fresh fish at different temperatures.*

culated according to the fact that lowering the storage temperature 6° to 7° C. has the effect of reducing the rate of spoilage by about 50 percent. The dotted curves demonstrate spoilage at 0° C. after storage at a higher temperature. Fish that can be kept 14 days at 0° C. can be kept only 4½ days at +10° C., and 1½ days at 20° C. The higher rate of spoilage at higher temperatures is effective from the moment the fish is killed, and storage of fish at a certain temperature always reduces its "storage life" at another. As an example, freshly caught fish stored at 20° C. for 16 to 18 hours keep only half as long at 0° C. as fish chilled to 0° C. immediately after they are caught.

As to the commercial handling of fish, Figure 37 shows the rise of temperature in fish which are landed, taken out of the ice, and sold in the market. The storage life at 0° C. is probably reduced two or three days by this kind of treatment.

Different species of fish have different keeping qualities. Cod, haddock, Norwegian winter herring, and flounder keep 12 to 15 days in good condition when cooled to 0° C. immediately after they are caught and stored at this temperature. Halibut, salmon, and some other species can be kept 18 to 20 days at 0° C.

Fish are usually chilled by ice, of which huge amounts are used aboard fishing craft and in fishing ports. By direct contact with liberal amounts of ice the fish are chilled rapidly, usually to about 0° C. within 12 to 24 hours, depending on the size of the fish and its

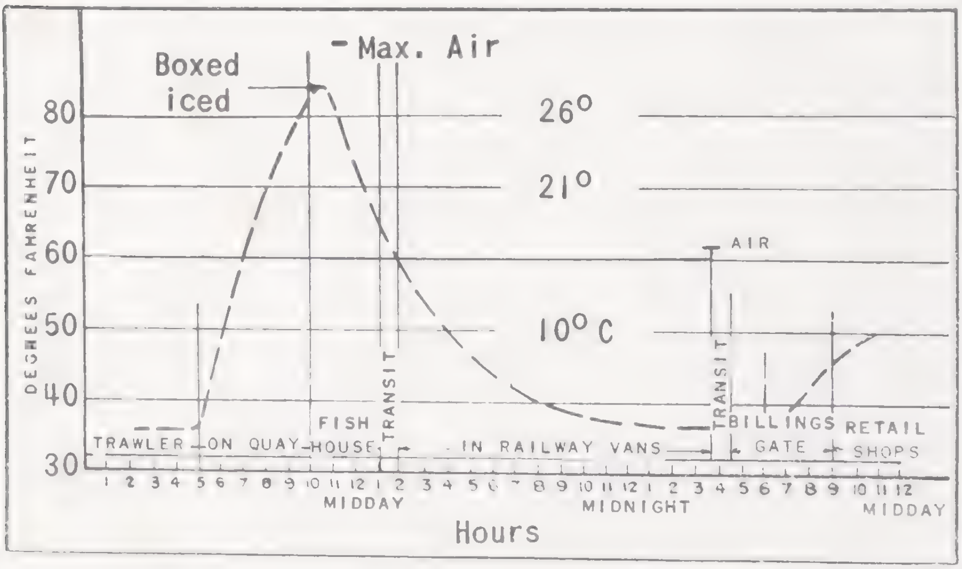



*Figure 37. Average temperature of fish during time on wharf, in transit and in market. (Courtesy of Torrey Research Station)*

original temperature. Chilling can be done faster with circulating brine of 0° to —2° C., but this method is more complicated and not in common use. Air-cooling in different ways has been tried without success. It does not chill the fish as fast as ice, and tends to dry the surface of the fish. Fish, packed in boxes, are cooled and kept moist by liberal amounts of ice during storage and distribution. The amount of ice should be sufficient to last until the fish reach the retailer, for the ice is a cold reserve when the boxes are exposed to higher temperatures during transport and distribution.

For the storing and transport of fresh fish over longer distances, ship holds are normally kept at about 0° to —2° C. by mechanical refrigeration, while railway cars are mostly cooled by ice, an ice-and-salt mixture, or just insulated. In good insulated cars, the cooling capacity of ice already on the fish is considered to be sufficient to keep the fish near 0° C. for a couple of days. For transport to more distant markets, extra ice can be placed around and over the cases. Most fishing craft use ice in liberal amounts to keep the fish cool during fishing and transport to the market; very few have mechanical refrigeration.

Fresh fish on sale in retail markets of Europe often seem to be insufficiently chilled. They are often displayed without any ice or refrigeration at all, and may deteriorate as much in a day in the retailer's shop as they do in a week at 0° C. Improved quality can be achieved to a great extent if the retailer uses sufficient ice or refrigerated storage.

Ordinary round and eviscerated fresh fish are the most important chilled fish products, but fresh fillets are being used more and more. Fresh fillets are usually packed between layers of moisture-resistant paper, with ice in the bottom and on the top of the cases.

Some other fishery products, such as salted fish, klipfish, matjes herring, and smoked herring, are also chilled and stored at temperatures between +4° and —5° C. In this way they can be kept in good condition many times longer than at ordinary temperatures.

## Freezing

Freezing prevents the processes which are the main cause for spoilage. A frozen fish can be kept in good condition for a long time at proper temperatures, but freezing and the subsequent storage may cause other changes which are undesirable, and may make the fish less palatable than the fresh product. These changes may be due to the raw material, the pretreatment, the freezing methods, or the storage conditions. It is the aim of modern research and refrigeration to find the principal causes for these changes, and to reduce them to the minimum.

The most important changes in lean fish result in a drier and more fibrous product, which loses some of its juice when it is thawed and subjected to moderate pressure. The cause seems to be denaturation of the proteins, which lose their ability to swell and absorb the muscle juice and to return to their original condition. Other changes, such as dehydration and oxidation, seem to be of less importance for lean fish, and may be prevented by moisture-vapor proof packages and by glazing. The freezing rate was originally supposed to have the greatest influence on the loss of juice and denaturation. This was explained by the fact that the ice crystals formed by slow freezing were much larger than those formed by quick freezing. The larger ice crystals was said to rupture the cell walls and cause the loss of juice. Since then, it has been shown that this mechanical explanation is insufficient: colloidal changes in the proteins seem to be the principal cause for loss of juice and fibrous consistency. It also has been shown that the storage temperature has by far the greatest effect on maintaining the quality of frozen fish. Besides this, the freshness of the raw material has a considerable influence on the quality after freezing and the keeping properties in storage. Proof of this has been demonstrated by experiments made in 1937-38 at the Norwegian Fishery Research Station in Bergen.

Table 6.—Grading System for Frozen Fish

| Grade | Taste | Grade | Consistency |
|---|---|---|---|
| 1 | Excellent, as fresh | 1 | Excellent, as fresh |
| 2 | Good, but not quite as fresh | 2 | Good, a little dry |
| 3 | Fair, definitely not as fresh | 3 | Fair, definitely dry |
| 4 | Poor, fitness as food doubtful | 4 | Too dry, fitness for use doubtful |
| 5 | Very poor, unfit as fresh fish | 5 | Very dry and fibrous, unfit as food |

It is important to prove that there is some reliable correlation between sensory judgments of the quality of fish and the objective testing methods found to be most promising. Organoleptic examinations were made according to the scheme illustrated in Table 6; at least three persons gave their marks independently of each other. This scheme was worked out in 1948 and there may be others now which are better. As objective testing methods, determination of the amount of free "drip" by thawing and of the amount of juice expressed by applying a pressure of 0.75 kg $cm^2$ on the thawed fish

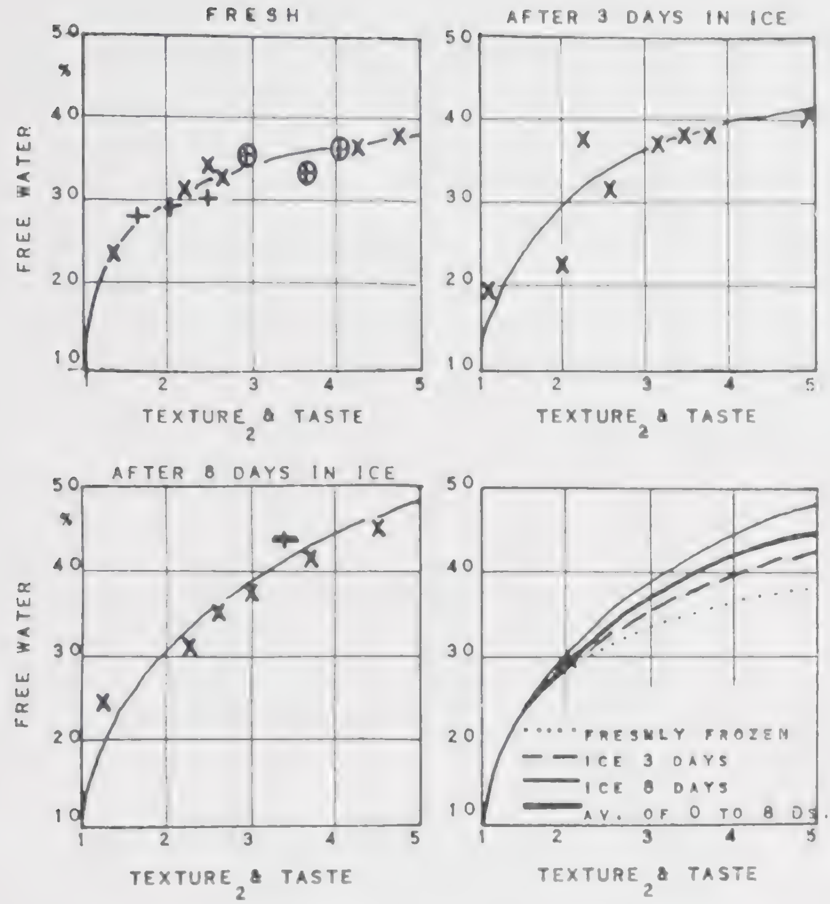



*Figure 38. The relationship between "fresh water" and taste plus texture.*

for two hours were used. Figure 38 shows how the sensory-judged quality marks agreed with the amount of drip plus press juice for frozen fish from raw material of different freshness.

On the basis of these determinations, results were obtained which are summarized in Figure 39. The different freezing times used, 15 minutes to 8 hours for fillets of 4 cm. thickness (freezing rate after Plank 8 to 0.25 cm/hr), had very little influence on the quality. The storage temperatures, —20° and —9° C. much more importantly affected the quality of the fish after storage for one month or more. The freshness of the fish had a greater influence on the quality of the frozen product than had the freezing rates used. However, very slow freezing, 26 hours (or 0.077 cm/hr), resulted in a product definitely inferior to samples frozen in eight hours or faster.

High storage temperatures were used in these experiments. An

other series of cod were frozen on higher freezing rates, and stored at lower temperatures. Ice crystals were measured and microphotographs made of the fresh and frozen samples.

Figures 40 to 46 (see pages 122-123) show the effect of the rate of freezing on the texture of the fish muscle. Larger ice crystals are formed at the slower freezing rates.

Figure 47 (see page 124) illustrates the measured lengths of the ice crystals, immediately after freezing and after five-months' storage at —20° C. The faint drawn lines indicate the distribution of the measured values. The increase in length of crystals during storage is about proportional to the initial length.

The effect of these very different freezing rates and of the size of ice crystals upon the quality of the frozen product was not very pronounced. Figures 48 to 51 (see page 125) illustrate the results of the

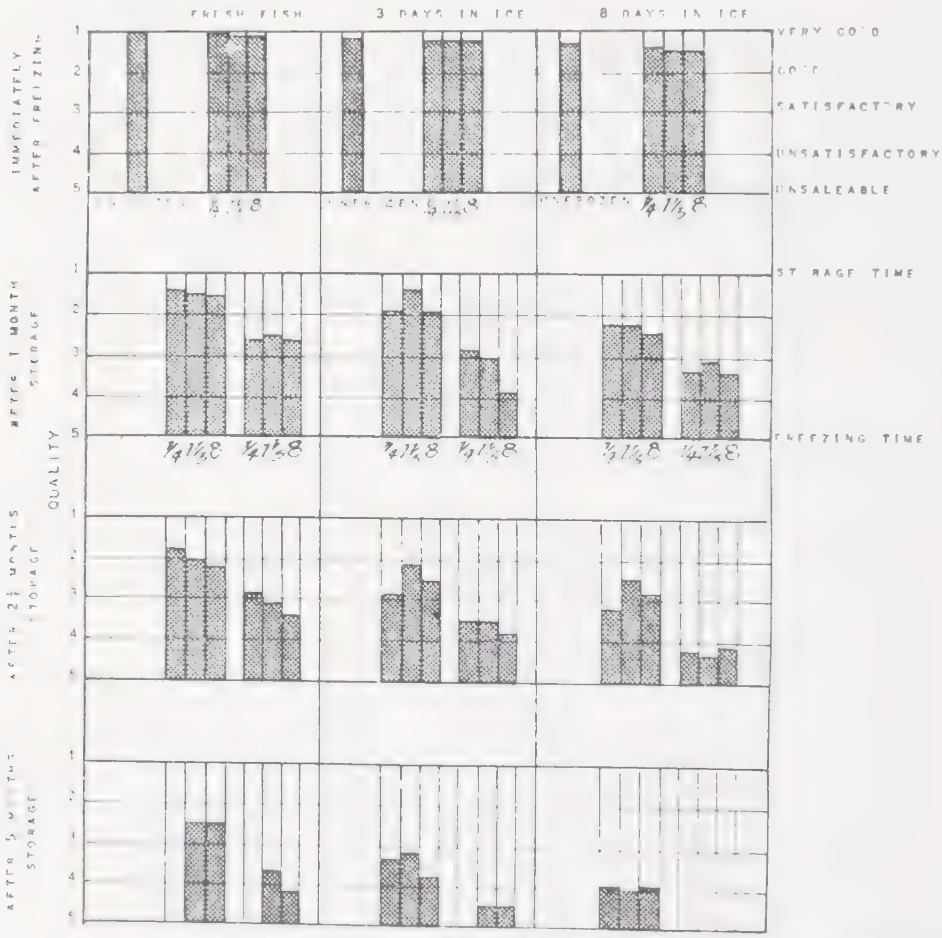



*Figure 39. A study of the influence of freshness of cod on the quality of the frozen product and the storage temperature.*

quality tests: Freezing causes some changes in "drip" and "press" in all samples, but the *differences* in the subjective tests judged by consistency and the amounts of drip and press juices are very small and varying. The differences are, in fact, astonishingly small considering that the fastest freezing rate was more than 800 times faster than the slowest. The size (volume) of ice crystals varies about as 1:200. Tests after storage give about the same picture.

These experiments confirm the findings of many other workers, who also have found that the freezing rate and the size of the ice crystals are of minor importance in relation to the quality of the frozen fish when freezing is reasonably rapid. Earlier experiments carried out in the Norwegian Fishery Research Station show that the freezing rate should not be less than about 0.3 0.25 cm hr, that is, the freezing time should not be more than eight hours for 4 to 5 cm. thickness. It is evident, then, that the rate of freezing within this limit causes a small but insignificant reduction in the quality of frozen lean fish as compared with the effect of freshness of the fish being frozen.

On the other hand, much information has been gathered which shows that the storage temperature is of decisive importance in the preservation of the quality of frozen fish. Figure 52 (see page 126) illustrates, for instance, how the rate of denaturation of proteins is reduced when the temperature is low. Storage experiments have shown a much better conservation of quality at —28° C. than at —20° C. It has also been shown that when stored for nine months at —50° and —65° C. cod and saith fillets changed little in quality. It is evident that all processes which change the quality of frozen fish are retarded by lower temperatures, and the rate of deterioration seems to be reduced to about half when the temperature is lowered 6° to 7° C. Based on numerous tests, curves, as shown in Figure 53 (see page 126), may be drawn to indicate the storage limit for frozen fish at different temperatures. Such limits depend upon many circumstances, including the strictness of quality claims. They will be different for different countries and for different districts and markets in the same country. They also depend upon the kind of fish frozen and upon the quality of the fish when frozen. The curves *indicate*, however, which temperatures are necessary for a given storage period, and they may be used to judge how long frozen fish can be kept at one temperature when the keeping quality is known at another.

The storage life of fatty fish such as herring is supposed to be a little shorter than that of lean fish, because of the development of rancidity. Also, the storage temperatures indicated are much lower than are commonly used for frozen fish in European cold storages. Minus 22° C. is required for storing lean fish up to six months from the time it is frozen, and —28° C. for 12 months.

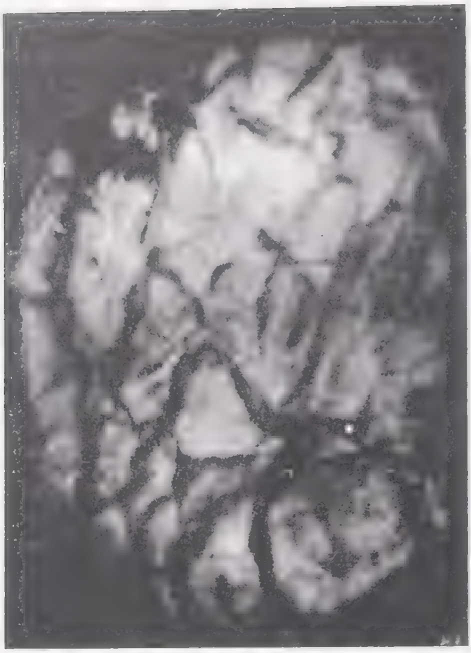


*Figure 40. Fresh unfrozen muscle.*

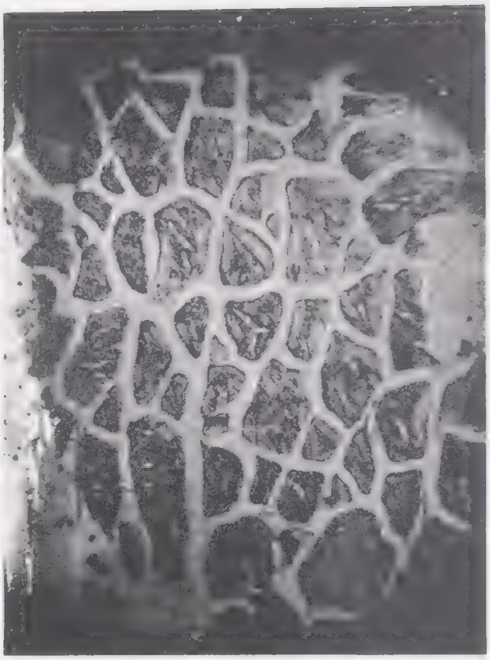
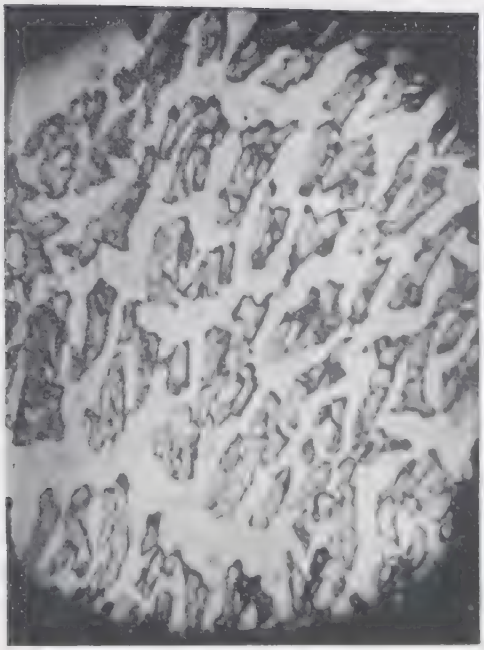


*Figure 41. Fresh unfrozen muscle after staining and fixing in paraffin.*

*Figure 42. Frozen between blocks of dry ice at rate of 52 cm./hr. (1.5 min. to 2.6 cm.)*

*Figures 40-46. Photomicrographs of cross section of fish muscle frozen at different rates. (All sections except Figure 40 were stained and then fixed in paraffin.)*



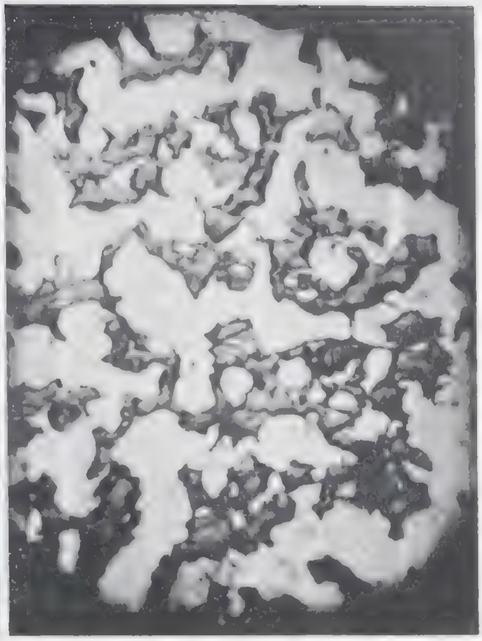
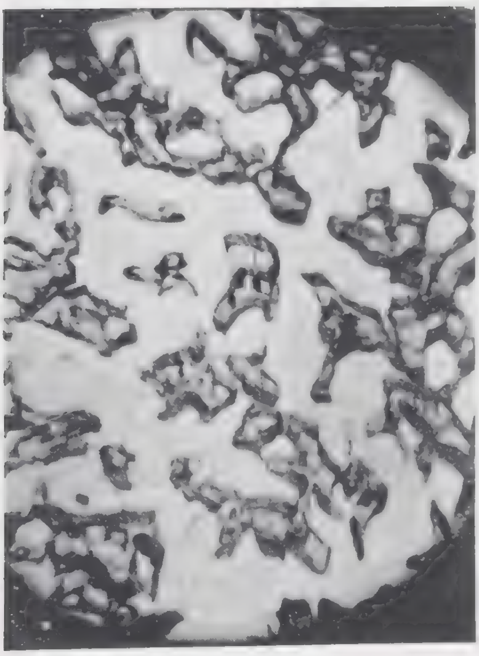


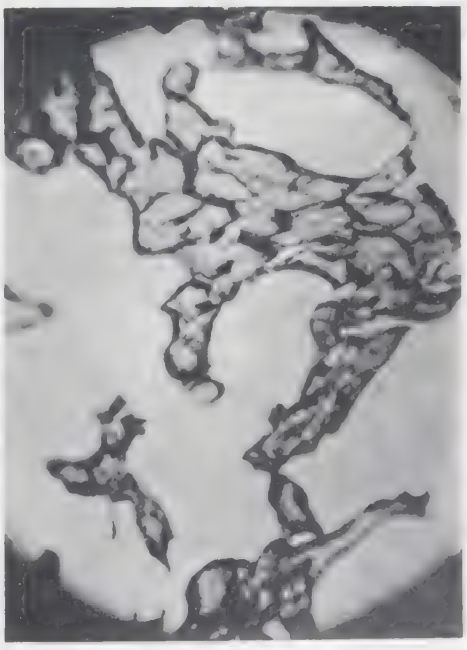
*Figure 43. Freezing rate 5 cm* [illegible]

*Figure 44. Freezing rate 1.7* [illegible]

*Figure 45. Freezing rate 0.61* [illegible]

*Figure 46. Freezing rate* [illegible]





## *Practical Freezing Problems*

Fish may be frozen in the round, gutted, eviscerated and headed, or as fillets. Herring, mackerel, halibut, and flounder are usually frozen round in Europe, while cod, haddock, and saith are for the most part filleted, but to some extent frozen round. Most of the fish fillets produced in Europe are made from cod.

The bulk of the fish used for frozen fillets in Iceland, Norway, and Denmark are freshly caught cod, delivered to the plants the same day as caught. To some extent fish a couple of days old delivered from trawlers may be used, or the fish may be transported to the freezing plants from the small fishing harbors where it is landed. In this case, it is packed in boxes with ice in the same way as fresh fish, so as to conserve the quality and to avoid bruises.

The filleting of fish is usually done by hand, but machines are used to some extent. The best-known and best-developed filleting machine is that of Atlantic Coast Fisheries in Boston, Massachusetts, U.S.A. It has a capacity of about 20 to 25 metric tons of fillets an eight-hour day. Filleting machines made before the war by the Germans have been used in Norway, but they have not been very effective and reliable. Other filleting machines for cod are under test and construction.

Fillets may be produced with or without the belly flaps, skinned or not skinned. The skinning of fillets in Norway is mostly done by machines. After skinning and washing, the fillets may be "brined," e.g., dipped for a short time in a solution of ordinary salt or other chemicals. Brining swells the surface somewhat, and helps to prevent drip when the frozen fillets are thawed. Fillets are usually wrapped in cellophane or waxed paper and placed in cartons before they are frozen.

For the freezing of fillets, freezers of the multiplate type are perhaps most used in Europe, but freezing tunnels and sharp-freezers are also used, some of them fitted with finned metal plates to improve the transmission of heat to the air. Air-blast freezing of fillets is more developed and used in North America than in Europe.

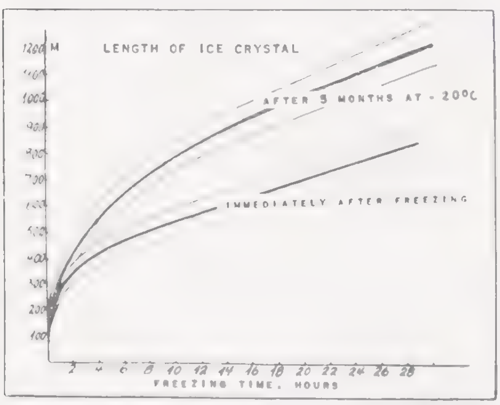



*Figure 47. Relationship between rate of freezing and length of ice crystals formed.*

For freezing round and gutted fish, sharp-freezers, blast-freezers, and brine-freezers are most common. Sharp-freezers are still much used in North America. For herring the Ne-

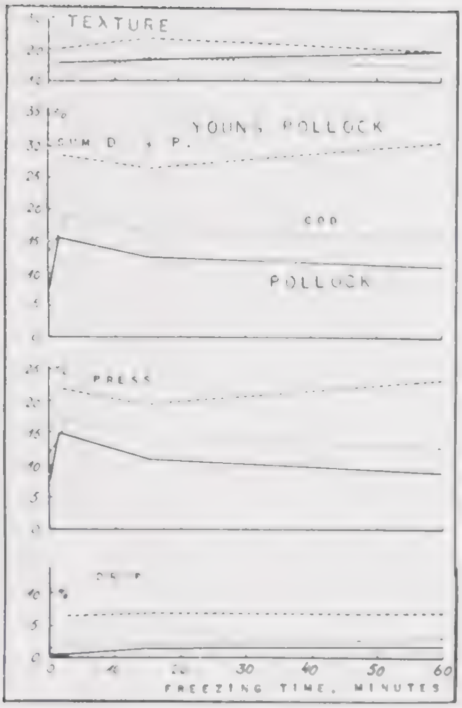



*Figure 48. Effect of rapid freezing on texture and drip of pollock.*

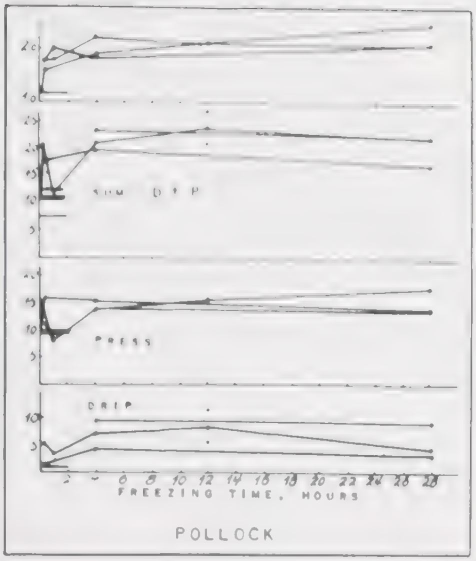



*Figure 49. Effect of slow freezing on texture and drip of pollock.*

*Figure 50. Effect of rate of freezing on texture and drip of cod.*

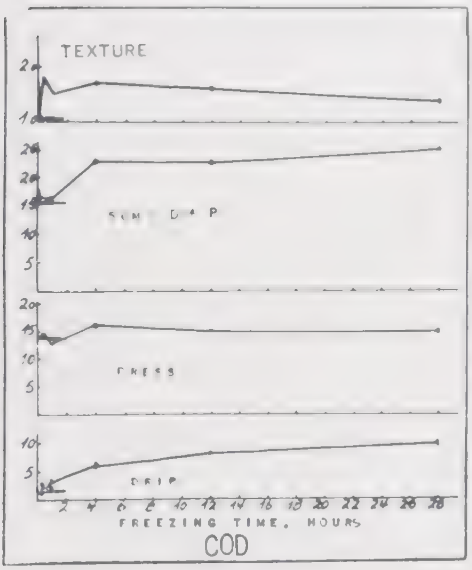
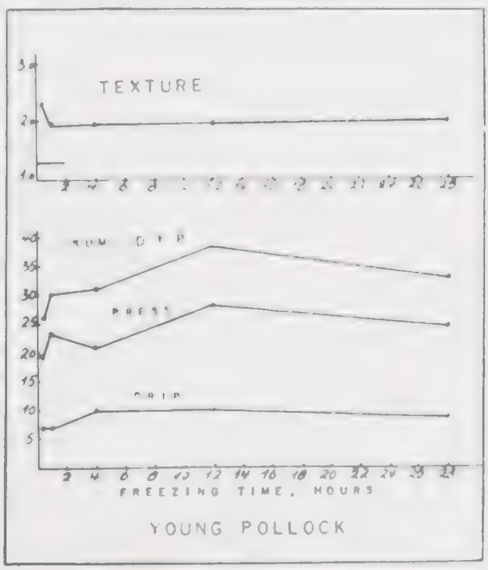



*Figure 51. Effect of rate of freezing on texture and drip of young pollock.*



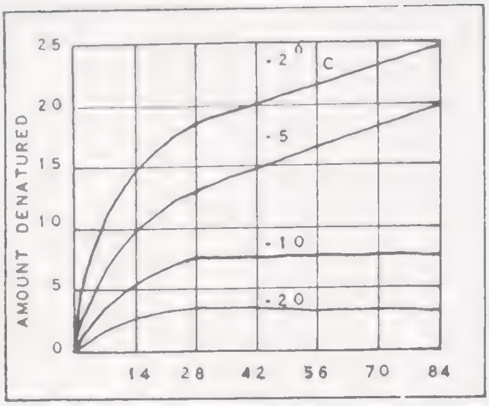



*Figure 52. Denaturation of protein of fish during storage at —2°, —5°, —10°, and —20° C. (Courtesy of D. B. Finn)*

colay Dahl brine-freezing method is much used in Norway. This direct immersion method provides fast freezing, but has the disadvantage of direct contact with the brine. Most of the herring frozen by this method are used for bait. The freezing process should include cooling the fish to the required storage temperature. When the frozen product is packed and piled up, it takes a very long time to get it down to the storage temperature, if this has not been accomplished in the freezer.

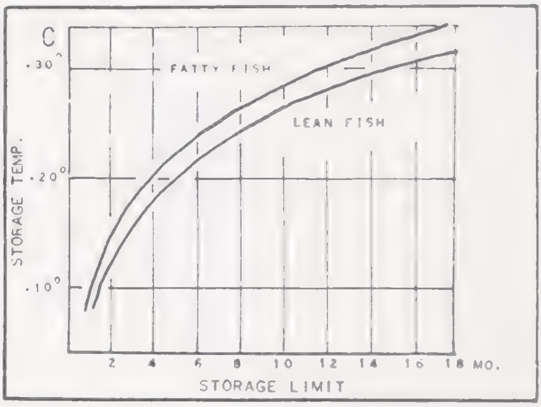



*Figure 53. Storage limit for frozen fish at various temperatures.*

Very low temperatures are also necessary for the transport and distribution of frozen fish and fish fillets. Refrigerated ships, cars, and trucks must be used, and cold stores with sufficiently low temperatures must be available near the market. Retailers should also have freezing cabinets where they can store the frozen fish at proper temperatures.

These last links in the refrigeration chain are often lacking in Europe, and the distribution of frozen fish cannot be satisfactory without them.

The production of frozen fish has developed greatly in some countries since 1939. Table 7 shows approximate data for Iceland, Newfoundland, Norway, and the United States of America. High production in countries outside the United States may be a result of the great demand for food during and after World War II, but much of the frozen fish is not as good as it ought to be, and distribution in Europe does not seem to be quite satisfactory.

Frozen fish, and especially frozen fish fillets, may, however, be produced and conserved in a quality that compares very well with the best fresh product, and is far superior to the big quantities of more or less stale "fresh" fish which is available. If the fish are produced,

TABLE 7.—PRODUCTION OF FROZEN FISH AND FISH FILLETS IN SELECTED COUNTRIES, 1932 TO 1947

| Country | 1932 | 1939 | 1943 | 1946 | 1947 |
|---|---|---|---|---|---|
| | | | *Thousand metric tons* | | |
| Iceland | 0.3 | 2.2 | 15.0 | 35.0 | 35.0[1] |
| Newfoundland | — | 3.2 | 5.5 | 15.0[2] | 7.5 |
| Norway | 6.0[3] | 11.0 | 30.0[1] | 22.0 | 31.0 |
| United States of America | 12.0 | 83.0 | 112.0 | 120.0 | 115.0[1] |

[1] Approximate
[2] Exports, fillets
[3] Mostly herring

stored and distributed properly, frozen fish have possibilities of being one of the finest and most-used fish products in times of normal demand.

## *CHILLED AND FROZEN FATTY FISH*

### *Rancidity in Frozen Herring*

Herring, which are extremely perishable, can be kept in first class condition by chilling with ice for only about 36 hours, and then only if large quantities of ice are used. As a result, with commercial chilling, much of the supply of herring reaches the consumer in poor condition. Some areas receive only small supplies and other none at all. Some fishing grounds, particularly those in the north, cannot be heavily fished because of their distance from the large consuming centers in the south, and there is the difficulty of sending herring there by rail so as to arrive in satisfactory condition.

British herring are at their best during the summer and autumn. The small quantities caught during the winter and spring are for the most part lean and of poor quality. In the past, heavy salting was used to carry over the abundant summer and autumn supplies to winter and spring, but salt-cured herring are no longer acceptable in Britain. The lack of an acceptable method of preservation reduces the present demand for herring by half.

Freezing and cold storage offers the best solution to these problems. Frozen herring can be transported over long distances in better condition than herring stowed in ice, and it may be at a cheaper rate. They can be stored at low temperatures and stocks can be built up

[3]Based on a paper presented by A. Banks. The work described in this paper was carried out by the Ministry of Food as part of the program of the Food Investigation Organization of the Department of Scientific and Industrial Research of Great Britain. The British Institute of Refrigeration. Session 1944-45.

during the summer and autumn for distribution during winter and spring. Many difficulties have to be considered, however.

The standards laid down on different occasions in Britain for the proper preservation by freezing of whitefish, cod, haddock, etc., apply equally well to herring. More than 50 percent of the United Kingdom's home supplies of these fish are kippered, i.e., lightly brined, dried and smoked, and since kippering shows up the effect of poor conditions of freezing and cold storage, it is essential that only the best methods be employed for herring.

Herring are caught during summer and autumn, for the most part, on three widely separated fishing grounds, off the Shetland Islands, in the Moray Firth, and off the East Anglian Coast. Fish are caught on the Shetland grounds and in the Moray Firth during June, July, and August, and off the East Anglian coast during October, November, and part of December. It is very doubtful that a central herring freezing factory can be established and operated satisfactorily. Permanent land establishments at the various ports may be uneconomical if they are operated for only a few months each year. It seems, therefore, that a transportable plant, possibly ship-borne, will be required to deal adequately and economically with herring catches.

Herring are being frozen in Britain by the air-blast and multiplate processes. Both of these processes, however, require considerable labor for satisfactory operation, and it is unlikely that they would be suitable for transportable plant. Research is being devoted to freezing these fish by more simple means.

Previous large scale commercial trials employed brine freezing on board a factory ship with disappointing results. The major difficulty was the development of rancidity in the herring during subsequent cold storage. This problem has been included in the research program of the Food Investigation Organization of the British Department of Scientific and Industrial Research since early days, and ways of preventing rancidity in frozen herring have now been worked out.

## Fundamental Characteristics of Herring Oil

Rancidity is caused by oxidation of some of the fat components. The reaction is spontaneous, but varies considerably in different fats, some are very stable in the presence of oxygen or air, others, are not. Fish oils, including herring oil, are classified and used as drying oils—they are fatty oils which oxidize easily when exposed to air. The oxidation of herring fat at low temperatures, producing oily flavors, is one of the difficulties of preserving herring for short periods by icing.

The oxidation of fats includes a number of complicated reactions, the first of which is the formation of a peroxide. Fat peroxides are

very reactive substances which can be quantitatively estimated by simple chemical means. Peroxide values are usually expressed as the number of cubic centimeters of standard thiosulphate solution equivalent to a weight of fat. The higher the peroxide value, the greater the oxidation. Peroxide values illustrate the oxidation of fats and the development of rancidity in fatty foods. They can be roughly correlated with change of flavor, but it is always wise to include sensory tests as well. Like most chemical reactions, the rate of oxidation of fats is affected by temperature — the lower the temperature the less the oxidation. Figure 54 shows the rate of oxidation of herring oil exposed to air in layers about 1 mm. thick at —5°, —10°, —20°, and —28° C.

Unfortunately, in this test, some oxidation had occurred during the extraction of the oil before the test was started. Nevertheless, the test shows clearly the effect of lowering the temperature on the rate of oxidation of herring oil. At —5° C. the formation of peroxide reaches its maximum rate after 45 days and at —10° C. after about 100 days. It is doubtful if the maximum rate was reached at the two lower temperatures before the end of the experiment. Taking into account the oxidation before the test began, it appears that little oxidation and little rancidity should occur in frozen herring during storage at —28° C.

## The Effect of Catalysts

The oxidation of fats is affected by a number of substances: some are pro-oxidants, which accelerate oxidation, other are antioxidants, which retard oxidation. Pro-oxidants include derivatives of the heavy metals, cobalt, manganese, lead, copper, and iron. Such metals may cause trouble if used in industries handling fatty foods. Initial tests with herring suggest that a pro-oxidant is present in these fish. Figure 55 shows the development of peroxides in herring stored at —20° C. and —28° C. after being frozen and treated in different ways.

There is a considerable difference between the rate of oxidation of brine-frozen and air-frozen herring, and likewise between glazed and unglazed herring. The difference between brine-frozen and air-frozen herring can only be explained by postulating the presence of a pro-oxidant in herring, which is activated in some way by the salt, which itself influences the oxidation of pure herring oil. Further tests to identify this pro-oxidant have shown that it is of biological origin, or at least is susceptible to heating. Figure 56 shows the oxidation of herring oil at —10° C. when emulsified with the flesh of lean herring (containing less than 2.5 percent fat) under different conditions.

It is clear that oxidation is much more marked when herring oil

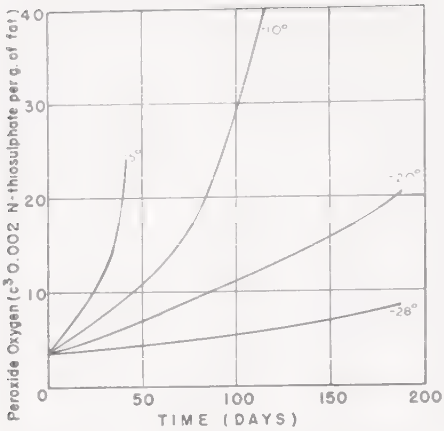



*Figure 54. Oxidation of herring oil in layers 1 mm. thick at different temperatures (°C.).*

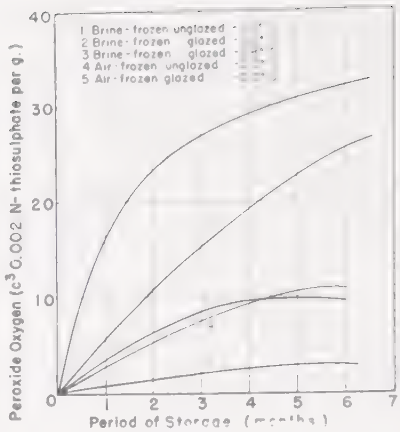



*Figure 55. The effect of freezing and cold storage on the oxidation of the fat of herrings.*

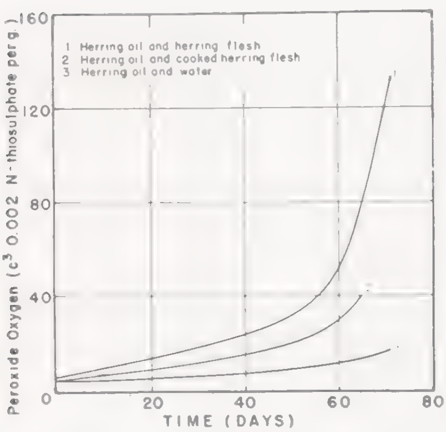



*Figure 56. Oxidation of herring oil emulsified with herring flesh at 10° C.*

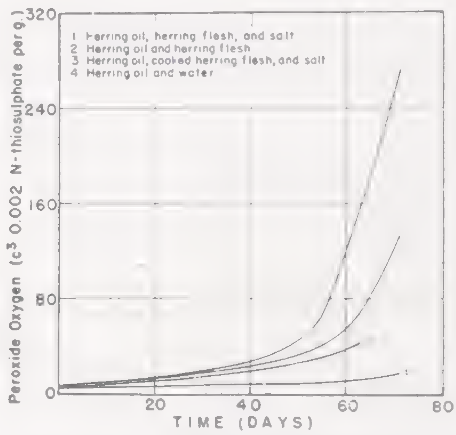



*Figure 57. Oxidation of herring oil emulsified with herring flesh at −10° C.*

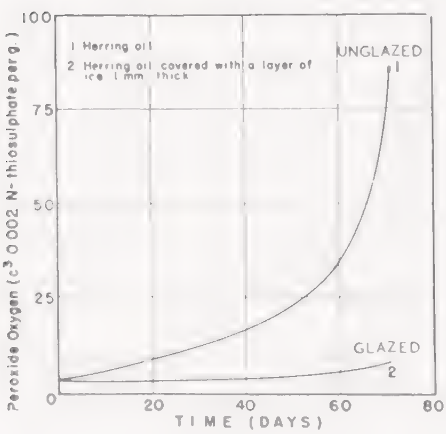



*Figure 58. Oxidation of herring oil in layers 1 mm. thick at —2.5° C.*

is mixed with fresh herring flesh than if it is mixed with cooked or heated flesh, and that oxidation under the latter condition is more rapid than the oxidation of herring oil emulsified with pure water. Further tests have shown that this fat pro-oxidation is concentrated in the colored muscle which runs parallel to the lateral line of the herring. It is now known that the colored components of this muscle — cytochrome, hemoglobin, and similar bodies — are responsible for the observed catalytic effect. Therefore, herring fat, despite its low rate of oxidation at —28° C. when pure, is especially prone to oxidation in herring and, therefore, to the development of rancidity, because it is in close contact with the lateral band of pigmented muscle.

### *The Effect of Common Salt*

Reference has already been made to the fact that herring frozen in sodium chloride brine becomes rancid during cold storage more quickly than herring frozen in air. Figure 57 shows the effect of salt on the oxidation of herring oil emulsified with herring flesh and held at —10° C. It is clear that the added salt enhances the effect of the pro-oxidants of herring flesh. Salt itself is not a pro-oxidant in the usually accepted sense, nor does it apparently affect the action of hemoglobin, cytochrome, and similar substances in liquid or unsaturated fatty acids at ordinary temperatures. It seems likely that the effect of salt on frozen herring is physical. Not all the water is frozen when herring are reduced to —30° C. and the presence of extra salt in the tissues increases the quantity of liquid still unfrozen at —20° and —30° C., thereby increasing the surfaces available for catalytic oxidation. This theory is supported, to some extent, by the fact that rancidity develops initially in brine-frozen herring in isolated centers within the colored strip of muscle.

### *The Effect of Glazing*

Experience gained during the war with the storage of dehydrated fatty foods has been that exclusion of air is the simplest and most effective method for preventing rancidity. Figure 58 compares the rate of oxidation of herring oil exposed to air at —2.5° C. in layers 1 mm. thick with that of herring oil covered with a 1 mm. thick layer of ice and exposed to air at —2.5° C. Oxidation of the "glazed" oil is much less than that of the "unglazed" oil. This agrees with numerous tests on frozen herring. Glazed herring always keeps better during cold storage than those stored without a glaze. Even brine frozen herring store well at —30° C. if the adhering brine is washed off, and if the superficial layers are then cooled and glazed.

## The Effect of Drying

Drying may be extensive during cold storage, and this has an adverse effect on the flavor of fatty fish. It is easy to see how drying promotes the development of rancidity. As the skin of the fish dries, it becomes porous, thus allowing free access of oxygen to the underlying fat. Glazing delays this process.

During commercial trials on the freezing and cold storage of herring, a study was made of the effect of drying on the development of peroxides in the fat of frozen herring. For freezing, the herring were arranged in freezing trays in a single layer and in a regular manner with tails interlocking in the center. Fish were frozen by both the air-blast and the multiplate processes. The air-blast frozen herring were glazed and packed in wooden boxes, each holding six blocks (19 kg.), without wrappers. The multiplate frozen herring were wrapped in waxed paper before freezing and packed in fiberboard cartons, also holding 6 blocks (19 kg). All the fish were stored at a temperature of about —29° C. in an air-cooled store.

The herring were examined after six-months' storage. Losses of weight of individual blocks of fish were determined. Fish in exposed positions in the package dried the most: the top block of a package of air-blast frozen herring lost 3.3 percent, while the center block of the same package lost only 0.7 percent. To examine the effect of drying, a top block and a center block from a package of air-blast frozen herring and from a package of multiplate frozen herring were each broken up into four samples. The first sample from each block consisted of the four herring which formed the edge of the block; the second, the four adjacent to those in the block; the third, the four fish adjacent to the second sample, and the fourth, the four herring at the center of the block. Table 8 shows results of the tests.

It is clear from this table that where drying is greatest, in the top block of a package or at the edge of a block, peroxide development is highest. The general level of peroxides in the top block of a box of air-blast frozen herring (loss of weight 3.3 percent) was higher (5 to 15.7) than that of peroxide (0.7 to 2.8) in the center block (loss of weight 0.7 percent). The peroxide value of herring at the edge of a block was always higher than that of the remainder of the herring, showing that the herring protect each other when frozen in the type of block employed. No comparison is made between the air-blast and the multiplate frozen herring because conditions of packaging and storage were not identical.

## Conclusions

As a result of many experiments, it appears that the temperatures recommended for the storage of whitefish (—20° to —30° C.) are

TABLE 8.—LOSS OF WEIGHT OF AND DEVELOPMENT OF RANCIDITY IN HERRING COMMERCIALLY FROZEN IN 3-KILOGRAM BLOCKS AND STORED AT ABOUT —29° C. FOR 6 MONTHS

| Method of freezing | Percent loss during storage | Position of block in container | Position of sample of herring in block | Peroxide value |
|---|---|---|---|---|
| Air blast | 3.3 | Top block | (1) 4 outside herring (edge) | 15.7 |
| | | | (2) 4 herring adjacent to (1) | 4.8 |
| | | | (3) 4 herring adjacent to (2) | 5.7 |
| | | | (4) 4 center herring | 5.4 |
| Air blast | 0.74 | Center block | (1) 4 outside herring (edge) | 2.8 |
| | | | (2) 4 herring adjacent to (1) | 1.2 |
| | | | (3) 4 herring adjacent to (2) | 1.2 |
| | | | (4) 4 center herring | 0.7 |
| Multi-plate | 1.5 | Top block | (1) 4 outside herring (edge) | 7.0 |
| | | | (2) 4 herring adjacent to (1) | 2.1 |
| | | | (3) 4 herring adjacent to (2) | 1.3 |
| | | | (4) 4 center herring | 2.2 |
| Multi-plate | 0.9 | Center block | (1) 4 outside herring (edge) | 6.2 |
| | | | (2) 4 herring adjacent to (1) | 0.3 |
| | | | (3) 4 herring adjacent to (2) | 0.5 |
| | | | (4) 4 center herring | 1.8 |

also suitable for herring. However, because the human palate is more sensitive to changes in the flavor of fats than to changes in the texture and flavor of whitefish, the storage life of herring for ideal preservation is slightly less than that of cod and haddock, three months as against four months at —20° C. and six as against eight months at —30° C.

Because British herring are so perishable, they must be frozen within 24 hours of catching. Otherwise, there is danger of the belly walls becoming damaged and of stale flavors developing during subsequent cold storage.

Herring must not be treated with salt or brine before freezing. Brine-freezing may be used, but the frozen herring must then be carefully washed and glazed before storage.

Glazing appears to be the simplest way of preventing rancidity during cold storage. Drying during cold storage can, however, adversely affect even glazed herring. Glazing may not be the complete answer to the problem of desiccation, but neither is the procedure

of wrapping in protective materials. Drying is by and large an engineering problem and should be approached from this angle.

The broad principles of the preservation of herring by freezing and cold storage laid down as a result of laboratory trials have been confirmed by pilot scale trials carried out by the Ministry of Food and the Torry Research Station during the war. The freezing procedure has already been described (page 127); the subsequent storage tests confirmed these conclusions.

## FROZEN SHELLFISH[1]

The material in this chapter is based largely on experience in the Netherlands, and will serve to illustrate some of the problems encountered in preserving shellfish by freezing.

### Shrimp

In the shallow waters along the Dutch coast, especially Zeeland and Friesland, there is an extensive fishery for shrimp. Shrimp are boiled on board immediately after catching (the concentration of salt used depending on future use). After landing, they are peeled by hand.

Freshly boiled, lightly salted, and peeled shrimp when quick frozen keep very well for five to six months at $-20^\circ$ C. In the course of storage, toughness increases, the fresh flavor is lost, and desiccation takes place. This causes the shrimp to taste like dried shrimp. The loss of fresh flavor could be partly prevented by omitting the salting on board, but this is not practical because the shrimp would then have to be cooked with salt after thawing in order to get the desired taste. The frozen product would thus differ from unfrozen shrimp and would not be commercially acceptable.

Desiccation can be prevented by filling the air spaces with dilute salt solutions (1 to 1.5 percent); this, however, amounts to about 60 percent of the net weight of the shrimp and tends to soak the shrimp when the package is defrosted. Therefore filling up the air spaces with a fluid can only be advised when long storage is anticipated.

### Lobsters

Lobsters, which are cultivated in Zeeland, have always been transported alive, packed in seaweed. Even with ice cooling, transport is difficult over great distances. But freezing live lobsters cannot solve

[1]Based on a discussion by C. J. H. van der Broek.

this problem as it makes the product entirely unacceptable. The changes caused by freezing are so very remarkable that the problem is difficult to solve. The most prominent feature in frozen lobster after cooking is the adherence of the flesh to the shell, which is very marked after one week, and increases during further storage. Even after very short storage periods the flesh can no longer be taken out of the shell in one piece, as it can from fresh lobsters after cooking. Apparently, the connective tissue directly under the shell contains a protein that is especially liable to denaturation. In the frozen state the flesh of the cooked lobster loosens very easily, while in unfrozen, cooked lobster it may adhere to the shell, depending on the biological state of the animal.

The uncooked flesh of the fresh lobster is rose-red; immediately after freezing it is yellowish-white, but in the course of 17-weeks' storage the original color returns gradually, though not entirely. There seems to be no explanation for this phenomenon.

## Mussels

Mussels are fished in Zeeland between the North Sea islands and along the northern coast. They are not popular all over the country, but in Rotterdam and Zeeland consumption is of some importance. A great part of the catch is exported to Belgium. Since mussels are a cheap product, they are cooked and taken out of the shell to decrease the weight to be frozen.

Some experiments have been made with cooked mussels. Freezing does not affect the taste or flavor to a large extent, but protein denaturation plays a very important role. By far the most prominent alteration is that of the mantle, which becomes mealy and falls to pieces, making frozen, cooked mussels rather unacceptable. However, some samples sent to customers were received very favorably because of the excellent taste and flavor. The alteration caused by freezing is so great that the difference between high and low freezing velocity and between high and low storage temperatures played an unimportant role. Slow freezing was advised in cases where no other methods were available, and very low storage temperatures, were not advocated.

## Oysters

Oysters are one of the chief export industries of Zeeland. They are considered to be of superior quality, and are exclusively consumed raw, served in the shell.

Freezing in the shell produces a very poor product, as has been shown with another kind of oyster in North America. Taken out of the shell and quick frozen in small packages of 12 oysters in a waxed carton, a relatively good product was obtained, which could be stored

for three to four months at —20° C. There is, however, a considerable alteration caused by freezing. The texture loses its crispness and the flesh becomes flabby (in this respect the oyster is the only seafood which resembles fruit in its freezing alterations). A little toughness is observed, but by far the most prominent is the alteration in taste. The salty, metallic, and sweet tastes seem to become separately noticeable instead of being combined into that special taste of the fresh delicacy. To a connoisseur, these alterations make the frozen oyster unacceptable, but many ordinary customers, reasonably well acquainted with oysters, judged the frozen oyster very good, and sometimes even better than the unfrozen. This may indicate that the judgment of experts should not always be relied upon, but that consumer research should, in some cases, play an important role. For example, North American judgments, cannot be compared to those in the Netherlands, because in North America oysters are usually cooked before eating. Therefore the American reports referring to a storage life as long as nine to twelve months at —20° C. are understandable.

Protein denaturation is apparently the cause of the changes which occur when shellfish are frozen. In spite of the work that has already been done on the denaturation of protein by freezing, very little is known about the fundamental chemical processes. This problem remains one of the most important in the freezing of animal tissues, the more so because this process seems to be the only one which has no equivalent—as far as it can be understood at this stage—in any other branch of protein chemistry or food technology.

## REFRIGERATION OF FRUITS AND VEGETABLES AT TEMPERATURES ABOVE FREEZING[5]

The fruit and vegetable crop has a very high monetary value, especially in relation to its weight. Definite figures are difficult to obtain for Europe, but the United States of America figure is $2,500 million. This emphasizes the need to take care of these products. In spite of the big expansion of the canning, freezing, dehydration, and preserve industry, a substantial part of the crop is marketed fresh. It is probable, however, that the best way of saving the fruit and truck crops is through the preservation industry. All means to stimulate, improve, and extend this industry should be undertaken. This is especially true today, when nutrition research, in collaboration with that of the machinery and packaging industries, has definitely improved production methods.

It is important to remember that only a small percentage of fresh

[5]Based on a paper presented by G. Borgström.

food reaching the consumer is eaten as such. Many products bought fresh are cooked. Since the art of preparing foods is very deficient in many homes, this, in many cases, means large additional losses in nutritional value.

Some figures from the United States may indicate a favorable trend in the better utilization of fruits and vegetables. In that country, 24 percent of the strawberries are frozen, and 75 percent are consumed fresh. The corresponding figures for spinach are 49 percent canned, 17 percent frozen, and 34 percent fresh. This may be the answer to the distribution losses of these perishable products. Still more surprising are the figures for peas, where 72 percent are canned, 18 percent frozen, and only 10 percent sold fresh to the individual consumer.

## Refrigeration

Most of these methods rely, to some extent, on the use of refrigeration, which is expensive. When refrigeration is used, it should be so handled as to give effective results.

Moreover, cold storage in long-range practice has some shortcomings. Some of the physiological disorders which occur are due to the influence of volatiles being produced and accumulating in the storage air. Others are more directly due to the low temperature. For some products, there are specific temperature effects which are of vital importance in the practical application of cold storage. A good example of this is pears.

For most pear varieties, there is a vast temperature range creating aberrations in the later ripening processes. For some varieties, this reaches right down to the immediate vicinity of 0° C. The longer pears are stored, the narrower is the risk zone, but the higher is the temperature above which normal ripening can be done.

Only short-range storage can be provided for berries and leafy vegetables. Deciduous fruits, root crops, and potatoes can be stored longer. The general level of respiration determines to which of these groups a product belongs. The intensity of respiration and the available chemicals being consumed by respiration fix the limit for the keeping quality of a plant product. The primary aim of cold storage is to put a brake on respiration, and so increase longevity.

An important anomaly exists in the respiration of all fruits and many vegetables—a climacterium or manifold rise in respiration intensity. This respiration maximum coincides in apples with the development of the aroma and the excretion of wax. It can be induced by the ripening hormone of fruits, which is identical with ethylene. The physiological effect of this volatile is such that it can almost be considered to act reversely to low temperatures. It stimulates respiration and transpiration, breaks down the chlorophyll, enhances ripening and aging, softens the tissues, and decomposes starch.

This also raises the question of co-storage or simultaneous storage of fruit at diverse ethylene producing levels due to different stages of ripeness, or storage with different kinds of products, as, for instance, pears and/or apples with bananas, potatoes with fruits, etc. A British scientist observes that Cox's Orange Pippin apples stored together with Worcester Pearmain apples decreased the storage life of both from 21 weeks to 8! The production of ethylene and other volatiles also explains the occurrence of several physiological disorders. It seems fairly well established that ordinary scald of apples is more frequent the earlier the apples are picked and put into cold storage. Some varieties are more susceptible than others. When brought to storage at the respiration maximum, apples are inclined to show cold-storage disease —lenticel spots, which seem to be caused by ethylene, chiefly produced in the climacterium. After this period, soft scald is a more common disorder.

This emphasizes the important fact that the developmental stage of a product, when stored, plays a vital role in its keeping quality. Knowledge of the most appropriate ripening stage is essential. The time of picking also has some influence, especially with berries, vegetables, and flowers. This, presumably, is interrelated with the sugar content. The storage technique is important. A warm-treatment at 18° C. for a couple of days in the middle of the third week extends the storage life of Victoria plums another three weeks, to a total of one and a half months. Methods for the practical application of these results are being studied.

Respiration evolves considerable quantities of heat. One ton of apples produces 1,500 kgcal/24 hr. (about 6,000 B.T.U.) at a temperature of 15° C., but at the freezing point 0° C. heat production is almost ten times smaller, (about 700 B.T.U.). Raspberries have an even more intense respiration. This signifies that more refrigeration is needed to cool raspberries effectively, and that the relative effect of lowering the temperature of the product is less marked. Peas and spinach form much more heat—10,800 kgcal. per ton per day at 16° C., and asparagus 20,000 kgcal. under the same conditions. The heat produced by one ton of asparagus corresponds to that emitted by burning 6 pounds (2.72 kg.) of coal. If this is calculated on the basis of the consumption of the plant's own fuel—sugar—one ton of peas consumes 1.4 pounds (0.64 kg.) sugar at 25° C., but only 0.2 pound (0.9 kg.) at 0° C. The main consequence is that a product brought into a refrigerated space may take a long time to cool, and very often it keeps a temperature above that of the storage room. It is not enough to bring the products into a refrigerated space to remove combustion heat. Spinach brought from the harvested field in the summer with leaves at a temperature of 30° C. into a cold-storage room of 2° C. does not cool to the vicinity of this temperature until

after two and one-half days. If not brought into a cold space, the temperature may, in many cases, rise several degrees above that at harvest.

Finely crushed ice or ice flakes packed around the products at the time of harvest, when packing or in the transport vehicle help to reduce the temperature. The icing is then extended all the way to the retailer, where the products are displayed. This method has been very little used in Europe, but many good results are reported from the United States, including extensive research findings. Icing strikingly reduces garbage losses of the leafy green vegetables with slow turnover rates. In several practical tests in the United States supermarkets, losses were reduced by more than half, as compared with those of the conventional dry display.

## The Icing Method

For effective cooling, the icing method has been further improved by the construction of special machinery for spraying with constantly ice-cooled water. This is particularly favorable with products having a high heat production such as asparagus, spinach, peas, cherries, and young carrots. Within ten to twelve minutes the same cooling is performed as by air-cooling for ten hours in an ordinary refrigerated storage room kept at 0° C. This method is often used for precooling before loading into refrigerator cars. Shipment can then be made immediately, saving time, ice, and switching charges. A chemical that inhibits mold and bacterial development is sometimes introduced into the cooling water to further reduce spoilage in fresh fruit and vegetable shipments. Sodium hypochlorite has been used for this purpose, and machinery equipped with an electronically controlled automatic metering device has been put on the United States market. Outstanding results have been obtained by cooling asparagus, celery, peas, and peaches in "hydrocoolers." Several quaternary ammonia compounds seem to be suitable for sterilizing the exterior of vegetables and some fruits.

Great improvement in quality can be made by removing the field heat of the products immediately after picking. This raises the question of the right time of the day for harvesting. From the restricted viewpoint of the temperature, picking should always take place late at night or early in the morning, but this rule is not altogether valid. The coldest part of the day often coincides with a period of heavy dew formation. This favors the growth of molds and bacteria, which most likely explains the controversial results obtained on this point. Effective cooling arrangements do, however, eliminate the importance of the picking time. But since, in many parts of Europe, growers lack efficient cooling resources, attention should be directed to the

advantage of harvesting products while they are cool. In some cases, good results can be obtained by leaving the products covered in the field until night and bringing them to the storehouses early in the morning. This is practiced at many places with apples and potatoes.

Mention should be made of some additional methods of cooling. Icing implies carrying a large bulk of ice—often amounting to two-thirds of the total load weight. This has directed attention to carbonic acid—or dry ice. But this chemical is rather expensive and there is danger of obtaining too low temperatures. On the other hand, carbon dioxide counteracts respiration and the development of molds. These effects have been used in the well-known gas storage method. In spite of some shortcomings, the dry-ice method has been used advantageously in air transport, where low weight is essential. It is economically advisable to use dry ice only on precooled products.

In the United States cooling of lettuce, spinach, etc., is also done by the evaporation of water. A portion of the surface moisture is removed when the vegetable is subjected to a vacuum. To cool 40 kg. of lettuce from a temperature of 24° to 0° C. it is necessary to evaporate only 0.16 kg. of moisture from the leaves. In commercial operation, an entire loaded car is placed in a vacuum tunnel and the final result is a temperature of —1° C. This is said to require 20 to 40 minutes per car, depending on the original temperature. This process provides for packing without body-icing, which avoids ice bruising, ice burn, and eventual discoloration from water soaking.

### *Gas Storage*

To a certain degree, storage in a carbon dioxide atmosphere can be considered an alternative to cold storage because of its specific effect in slowing down the respiration process. When tomatoes and lettuce are put in a carbon dioxide atmosphere of 5 percent at a temperature of 12° C., the result is quite as good as if these products had been kept all the time at 0° C.

Carbon dioxide retards the ripening and aging of fruits and counteracts the growth of spoilage fungi. Storage can be kept at a higher temperature without a corresponding increase in losses due to spoilage. Gas storage considerably extends the storage life of apples and pears. Much experimentation is needed, however, to establish the optimum concentration for each product or even each variety. A lower percentage of oxygen (2.5 to 10 percent) may be applied with a higher percentage of carbon dioxide (5 to 10 percent), or the method may be modified to decrease the oxygen content without a corresponding increase in the amount of carbon dioxide. This has proved most favorable for several apple varieties, including Cox's Orange Pippin. Gas storage methods have been worked out in their fundamentals at the Low Temperature Research Station at Cambridge, but many ex-

periments with apples and pears have been performed at the Horticultural Experiment Station, Blangstedgaard, Odense, Denmark, and at the private research institute of the Johnson Line, a Swedish shipping company. Successful trials have also been reported by British scientists with broccoli and cauliflower. Stored in an atmosphere of 10 to 11 percent of carbon dioxide, these products could be kept in a fresh stage for five or six weeks, while in ordinary cases they have to be marketed within four to six days.

For a good many products, the dangerous concentration limits are already known. Many varieties of apples and pears have been studied, and most demand a carbon dioxide concentration of 5 to 10 percent. Asparagus, cauliflower, peas, and strawberries need at least 20 percent of carbon dioxide in the atmosphere to retard respiration. Cherries need, according to United States investigations, 40 percent, and at a temperature of 10° C. such cherries have a better taste than those stored at 0° C. Peas stored in carbon dioxide keep 75 percent more of their sugar than those stored in ordinary air.

The discovery in the United States that treatment with carbon dioxide has a carry-over effect, makes the method more attractive in practice. By treating raspberries (Latham) for five hours, and strawberries (Weygate) for seven hours in an atmosphere of 45 percent carbon dioxide, the berries could be stored without fail for three days in ordinary atmosphere at 10° to 12° C. This method has also been used before transporting cherries and apples.

Storing trials have been made in a nitrogen atmosphere, altogether devoid of oxgyen. General, the results have been made because of definite changes occurring in the chemical metabolism of the products. But, according to prewar German investigations, there are some exceptions, as onions, blackberries, and beans.

### Use of Germicidal Agents

Another way of attacking the storage problem of fresh fruits and vegetables through the air is the addition of special preservative vapors or gases. Ozone, ammonia, nitrogen-trichloride, and glycol have been tried. The latter, which is so useful against air-borne bacteria, is altogether ineffective against molds and mold spores. Nitrogen-trichloride has been tried in Germany before the war, and in the United States of America with good results. Especially favorable transit results have been obtained with tomatoes, onions, and asparagus. Ozone diminishes mold spoilage to one-half in grapes, strawberries and cauliflower, but usually produces necrotic spots on apples. Scald has been reduced by the use of ozone on Rhode Island Greening apples from a frequency of 31.2 to 3.6 percent. Ammonia in a concentration of 1.5 to 0.15 percent is stated to be particularly effective on tomatoes. Ultraviolet radiation is supposed to

sterilize the air, but tests reveal that such high intensities are needed to kill mold spores that this method is of minor importance for this purpose. However, it has definite advantages for sterilizing the water used to wash the products before storage or transport.

### Desiccation

So far the survey of methods has covered the control of respiration. Control of shrinkage and spoilage are quite as vital to the storage life of fresh products. Berries and vegetables are 80 to 95 percent water. When 5 or 10 percent of the water content has evaporated, shrinkage becomes visible. The loss of water is accelerated either by transpiration or by favorable conditions for physical evaporation. The rate of both processes depends on the temperature and humidity of the surrounding air. Low humidity and high temperature favor high water loss. More water evaporates immediately after harvest than later. Comparatively warm products brought into a refrigerated space lose a considerable amount of water because of the sharp decrease in external vapor pressure. When taken from saturated air at 23° C. to saturated air at 0° C., the vapor pressure falls from 23.8 cm/Hg to 4.6 mm/Hg. This difference in the vapor pressure is, in fact, larger than between zero air as dry as 50 percent compared with saturated air. This stresses the importance of a rapid cooling from quite another viewpoint.

Ventilation alone causes a very small increase in the rapidity of evaporation, but low humidity of the circulating air hastens desiccation. This happens often in cold storage when the air passes the cooling coils and is deprived of a substantial part of its humidity.

### Prepackaging

Carrots are particularly sensitive to water losses and need at least 85 to 90 percent relative humidity. A well-managed fruit store should maintain 85 percent relative humidity. The most important new development in this field is the use of moisture-proof wrappings—various types of cellophane, Pliofilm, etc. This material is permeable by carbon dioxide, which passes through it ten to twenty times faster than air. Water vapor hardly escapes—water loss is often twenty to thirty times less. In most cases, the taste is not influenced by film wrappings.

To a certain degree also this method can be considered an alternative to refrigerated storage. In the United States experiments such as wrapped vegetables were stored at 12° C. with less weight losses than unwrapped products at 0° C. However, cold storage is also favorable for wrapped products. By a combination of wrapping and cold storage, extremely good storage results have been reported with vegetables

having heavy respiration such as asparagus and spinach. In the United States it has been found that orchard freshness of apples can be maintained for almost a year when shipping cases are lined with Pliofilm.

In a practical large-scale test of prepackaging vegetables performed at Ohio State University, Columbus, Ohio, U.S.A., in 1946, the total loss by spoilage in the observed shops showed an average decrease from 17.6 to 1.8 percent. U. S. experience also shows an increase in the sale of products prepackaged in this way. Packaging should be done in the production region. Transport is more economical when unnecessary parts are not carried, and trimmings can be returned to the soil.

## Waxing

The use of wax coatings on both fruits and vegetables has been extensively tried in Sweden, as a means of diminishing evaporation. It is commonly practiced on citrus fruits in the United States of America. The surface of the product is provided with a thin wax film about 0.00037 inch (0.01 mm.) thick, which does not entirely cover all pores—it admits a normal gaseous exchange for respiration, but impedes transpiration.

Many investigations have been performed on apples at the Cambridge Institute. The trouble has been to find a coating that decreases water losses, but does not interfere with respiration. The spray particle size is a major factor in determining the kind of film formed. Recent results from Cambridge report that 300 to 400 bushels of apples could be treated per day at a cost of 3½d. per 36 liters (bushel).

In many instances waxing is reported to have reduced decay. Excessive water loss reduces the vitality of the product, making easier the destructive work of decay organisms; the minute creases formed by shriveling are also ideal locations for the incubation of mold spores. In the United States, more than 30 percent of the citrus fruits, 80 percent of the tomatoes grown in Texas and Florida, a large portion of the cantaloupes, and most cucumbers shipped long distances for marketing are protected by wax coatings. The method reduces the weight loss of cucumbers by one-half.

## Fungus Diseases

It has been shown that air-borne germicides and waxing reduce mold attacks, and that refrigeration can be carried down to temperatures where the growth of spores, bacteria, and fungi is so very slow that the practical importance is nullified. There are, however, some mold varieties which are very little influenced by temperature. One of them, *Gloeosporium album*, is a foe dangerous to all fruit storage in Europe. It is a remarkable fact that the U.S. *Gloeosporium* common in fruit storage is another variety which is easily controlled by low temperatures.

The chief way of combating this disease is through improved sanitation in the orchards. Presumably *G. album* incubates on necrotic crinkles of tree branches. Disinfecting wrappers and skin coating may help. Careful handling of deciduous fruits is essential. Most cases of green and blue mold are accompanied by a rupture of the skin through which the spoilage fungi apparently enter.

## Effect of Growing Conditions

Growers have to be made storage conscious. The picking time is vital, but so is the variety grown. Fertilizing affects keeping quality. Products should, as a rule, have sufficient potassium and phosphorus, but restricted supplies of nitrogen. An increased yield through added nitrogenous fertilizers may mean a still larger loss in spoilage. Our knowledge is very deficient as to the keeping capacities of different varieties, but important studies have, however, been made with pears and apples. Some varieties of tomatoes can be stored twice as long as others. Another aspect is the keeping quality *after* storage. It is not sufficient for products to retain their appearances; they must withstand commercial handling afterwards.

## Limitations

What are the limitations to reducing storage and distribution losses? How far can they be reduced? Which losses are avoidable, and which must be counted as unavoidable?

As long as fresh products are alive they respire and give off water. At the same time, they absorb oxygen, partly compensating for the carbon dioxide emitted. There is difficulty in distinguishing between spoilage losses and real weight losses. Spoilage stimulates the production of carbon dioxide and is liable to increase the evaporation of water. The real weight losses can only be established through frequent weighing of enclosed samples.

The combined loss through spoilage and respiration-evaporation in the scientifically controlled Swedish apple-storage experiments was 5 percent per month, of which 3.5 percent constituted spoilage and 1.5 percent weight loss. According to calculations based on the respiration figures, the loss due to emitted carbon dioxide should be capable of reduction to 0.1 percent per ton per 24 hours, and the water loss to 0.12 percent. Thus, the observed weight losses should be diminished by at least two-thirds.

## Losses in Practice

It is startling to find how much waste conventional practices cause. U. S. authorities estimate that, on the average, one-fourth of the food

produced is never used for human nourishment, but is discarded or wasted somewhere along the line. It was found in the Swedish potato survey that 15 to 20 percent of the potato crop is wasted. Waste of fresh fruits and vegetables often reaches higher figures. Enquiry among retailers and wholesalers revealed losses of strawberries of 30 to 40 percent. More than one-third is lost in winter storage of cabbage and carrots.

The U. S. War Food Administration published the following rough estimates of loss on a percentage basis: deciduous fruits 26 percent, potatoes 28 percent, tomatoes and citrus fruits 33 percent, leafy green and yellow vegetables 43 percent. These high figures may, to some degree, be attributed to large transport losses in the United States because of great distances between production and consumption areas. This demonstrates the importance of locating production closer to consumption districts. The new horticultural drive in Russia seems to place great emphasis on arranging the production of fresh fruit and vegetables in zones immediately surrounding the cities.

In 1942 the United States wastage of fruits and vegetables after leaving the producer amounted to an average of 20 percent, or more than US$800 million at retail value. Prewar German estimates put their wastage at 16 to 18 percent. For the season 1946/47, Swedish potato losses amounted to at least 21.8 percent. All these figures call for a challenging re-examination of existing practices at almost every point.

## REFRIGERATED GAS STORAGE OF FRUIT[6]

The refrigerated gas-storage of fruit has assumed peculiar significance in the United Kingdom. In 1939 there was space for 40,000 metric tons of apples in gas storage throughout the country. More storage has been built since that time, but progress was retarded by the war. Further stores are in construction and others are planned.

Apples are not stored at 0° C. in ordinary refrigerated storage in England, as is usual in the United States, because such a temperature is unsatisfactory. It is a peculiarity of English-grown apples that most varities are damaged by temperatures below about 3.5° to 4° C. The damage often occurs in a comparatively short time: the flesh of the fruit breaks down and portions become water logged and turn brown. In the early days of refrigeration, before it became known that this damage was caused by "low-temperature breakdown," considerable losses were incurred.

The difference in the storage life of the apple, if low-temperature

[6]Based on a paper presented by W. Hugh Smith.

breakdown does not intervene, produced by a difference in storage temperature of 0° C. and 4° C. is very considerable. Were it not for the development of gas storage, the period during which English apples could be marketed would be very limited.

The development of gas-storage technique is an interesting example of how observations made in the course of purely academic research often lead to results of the greatest practical value. It had been noticed that increased concentration of carbon dioxide and reduced concentration of oxygen in the atmosphere depressed the respiration and inhibited the germination of seeds. How would it affect the whole fruit? The effect was found to be a depression of the rate of respiration and a greatly increased life of the fruit (Figure 59).

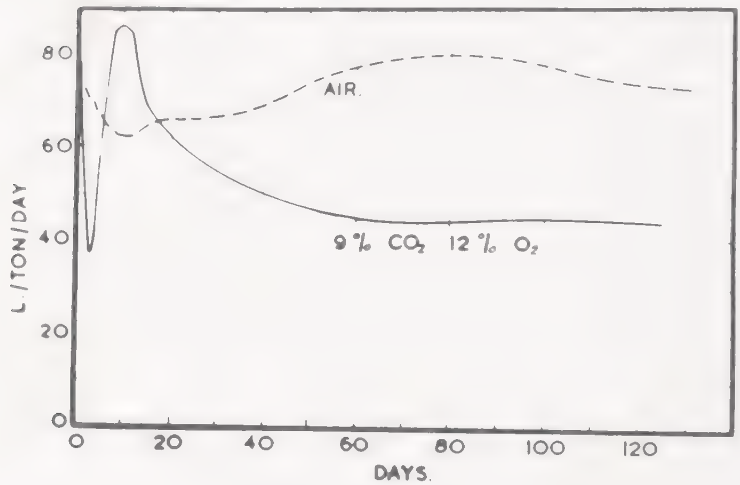



*Figure 59. Effect of increase in carbon dioxide and decrease in oxygen on respiration of King Edward VII apples (1947/48). (From unpublished data of J. C. Fidler)*

## Gas Storage

Gas storage is, in essence, a technique whereby the living fruit, which gives off carbon dioxide while it absorbs oxygen from the air, is allowed to build up a modified atmosphere in its environment. If an airtight compartment containing a quantity of apples is tightly closed, the apples will, in the course of time, use up all the oxygen and replace it by carbon dioxide. When the oxygen has been completely absorbed, there is 21 percent of carbon dioxide and no oxygen, the remaining 79 percent being nitrogen. It is possible, however, to interfere with this process. When the concentration of carbon dioxide has reached 8 to 10 percent, some air can be allowed to enter the compartment and, by regulating the exchange of outside air and inner atmosphere, we can maintain a concentration of 8 to 10 percent of carbon dioxide and 13 to 11 percent of oxygen. This, essentially, is what is done in gas storage.

The modern gas storage consists of a sheet-metal-lined chamber, its overlapping joints sealed with grease to make it as nearly gas tight as possible. The floor is also treated with a gas-proofing material. The chamber is insulated on the outside of the metal-sheeting and is refrigerated by an internal evaporator, usually housed in a central duct. Air is circulated over the evaporator coils by means of a reversible blower driven by a motor outside the room. The fruit, in clean orchard boxes, is deposited in the storage chamber through an opening which is later closed by a sheet metal door provided with a rubber gasket; the door is screwed on tight. Ventilation is adjustable.

It is, of course, necessary to know the temperature and concentration of carbon dioxide in the store room. This is achieved by means of a distant reading thermometer and a katharometer. The katharometer is an instrument which measures carbon dioxide concentration by change in the resistance of an electric wire in a tube through which a sample of gas is drawn from the store.

Under these conditions, at a temperature of 4° C., the Bramley's seedling apple, the chief British culinary apple, can be stored satisfactorily until late spring or early summer, whereas in cold storage the apples do not keep much after January without significant wastage. Gas storage extends the storage life of the apple by 50 to 100 percent.

Unfortunately, these conditions do not give the best results for many other varieties (Table 9). Cox's Orange Pippin may be cited as an example, since it is the most popular and valuable dessert variety in Britain. During extensive experiments made to determine the optimum conditions for each variety of apple grown in the United Kingdom, it was found that Cox's Orange Pippin requires a low concentration of carbon dioxide combined with a very low oxygen concentration—5 percent of carbon dioxide and only 2.5 percent of oxygen.

The most practicable means of achieving these conditions in the gas storage has been found. If the fruit is allowed to remove the oxygen from the store-room to the level of 2 percent, it is necessary to remove the excess of carbon dioxide (i.e., the difference between 18.5 percent and 5 percent). This is done by means of an absorbent. Some of the atmosphere in the chamber if by-passed through a cylinder in which there is a solution of either caustic soda or milk of lime. This frees it of carbon dioxide, and it is then returned to the chamber (Figure 60).

Cox's Orange Pippin apples, stored in this way, may often be kept until March, though it must be pointed out that a great deal of variation in keeping quality is found both from one farm to another and from one season to another.

Gas storage has also been employed successfully for the storage of pears. Three varieties have been tested: Conference, Doyenne du Comice, and William's Bon Chretien. Of these, Conference is the only one grown commercially on a large scale in the United Kingdom (Table 9). Conference pears grown under conditions in the United Kingdom can be stored in air at 1° C. for three and a half months. In 5 percent carbon dioxide with 2½ percent oxygen at 1° C. they keep for ten months, or in 10 percent carbon dioxide with 11 percent oxygen for seven months. Thus, refrigerated gas storage has a tre-

TABLE 9.—TEMPERATURES AND ATMOSPHERES RECOMMENDED FOR THE STORAGE OF APPLES AND PEARS GROWN IN ENGLAND [1]

| Variety | Type | Temperature | $CO_2$ | Oxygen |
|---|---|---|---|---|
| | | (. . °C. . .) | (. . . Percent | . . .) |
| **Varieties requiring control of temperature and of $CO_2$ only** | | | | |
| Apples | | | | |
| Bramley's Seedling | Culinary | 4 | 8–10 | 13–11 |
| Lord Derby | Culinary | 4 | 8–10 | 13–11 |
| Stirling Castle | Culinary | 4 | 8–10 | 13–11 |
| Pears | | | | |
| William Bon Chretien | | 0–1 | 10 | 11 |
| **Varieties requiring independent control of both carbon dioxide and oxygen, in addition to temperature control** | | | | |
| Apples | | | | |
| Lane's Prince Albert | Culinary | 4 | 5 | 2.5–5 |
| King Edward VII | Culinary | 3.5 | 5–10 | 2.5 |
| Monarch | Culinary | 1 | 5 | 2.5–5 |
| Ellison's Orange | Dessert | 1 | 5 | 2.5–5 |
| Cox's Orange Pippin | Dessert | 4 | 5 | 2.5 |
| Laxton's Superb | Dessert | 4 | 10 | 2.5 |
| Worcester Pearmain | Dessert | 1 | 5 | 2.5–5 |
| Allington Pippin | Dessert | 3 | 3 | 2.5 |
| Pears | | | | |
| Conference | | 0–1 | 5 | 2.5 |
| Doyenne du Comice | | 0–1 | 10 | 2.5 |
| **Varieties requiring control of temperature with ventilation to remove carbon dioxide** | | | | |
| Apples | | | | |
| Annie Elizabeth | Culinary | 1 | 0 | 21 |
| Newton Wonder | Culinary | 1 | 0 | 21 |
| Blenheim Orange | Dessert | 3 | 0 | 21 |
| King Pippin | Dessert | 4 | 0 | 21 |

[1] It is quite easy to damage apples by too high a concentration of carbon dioxide or by too low a concentration of oxygen. The limits of tolerance vary with the variety and with temperature

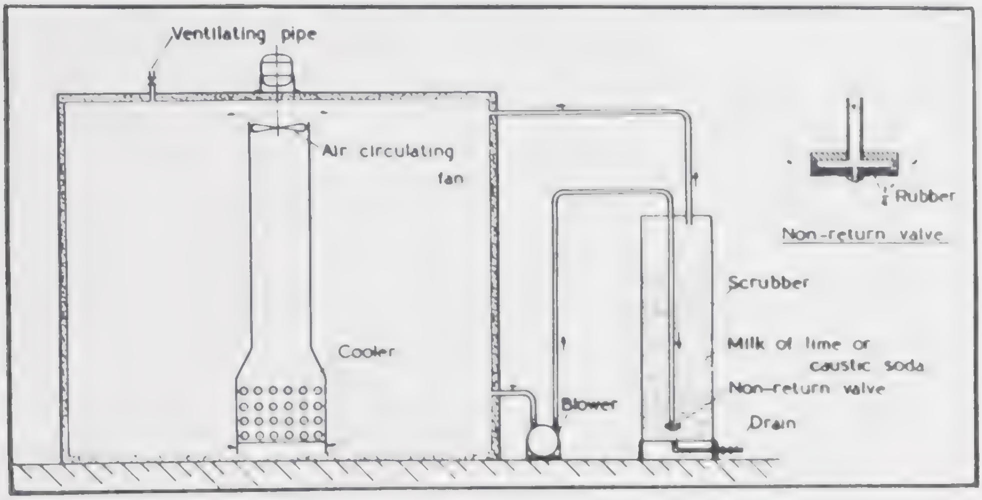



*Figure 60. Diagram of arrangement of gas storage and carbon dioxide scrubber.*

mendous advantage over ordinary refrigerated storage. Not only is there the advantage of greater storage life, but the market life of gas-stored pears (i.e., the time available between removal from store and the development of dessert quality is about twice that of cold-stored pears).

## *Importance of Maturity of Fruit*

Certain other conditions must be watched if gas storage is to be successful. One of the most important is the degree of maturity of the fruit at the time it is stored.

The question is often asked, "How can the maturity of fruit on the tree be determined?" Scientifically, maturity can be determined quite accurately: as the apple ripens there is a characteristic change in the rate at which carbon dioxide is evolved. This can be measured in the laboratory, so that a curve of increasing carbon dioxide evolution can be traced, noting a peak and then a decrease. At the peak (which for convenience is named the climacteric), the apples passes through a critical stage. When that stage has passed, the apple is of absolutely no use for gas storage.

Such a test cannot be applied in commercial practice, but fortunately there are distinct signs when the climacteric stage is approaching. A change in the ground color of the skin, a beginning to yellow, is the most obvious. Apples and pears may, however, be picked too early. If picked prematurely, they lack their full potential size and are likely to shrivel. Many varieties of apple develop scald if picked too early. Much depends upon the experience of the grower, but

there is a practical test of considerable value. As soon as the apple parts easily from the tree when given a slight twist, it is ready to pick.

Apples and pears may be stored too ripe, even if they have been picked at the right stage, for maturation proceeds until the fruit is cooled. Not more than four to five days should elapse between picking and sealing the fully loaded store. For that reason, it is not practicable to have chambers of more than 50 metric tons capacity. The storeroom must, of course, be filled. If it is really gas tight, there will be no difficulty in getting the correct concentration of carbon dioxide. But, in any case, the fruit must be *cooled promptly*.

No difficulty is experienced with humidity if the storeroom is constructed with an evaporator of adequate surface area to cool and maintain the fruit at the correct temperature, with a small temperature difference between the cooler surface and the fruit. But other constituents of the atmosphere must be considered. As the fruit approaches the stage of ripening, which is characterized by a peak in respiratory activity, there is an increased emanation of ethylene. If the concentration of ethylene is too high, it tends to hasten ripening, and it may cause some damage. There is no danger of this happening if the fruit is picked at the correct stage of maturity, stored promptly, and — what is most important — varieties are stored without mixing. An earlier-maturing variety stored with a later maturing variety may not only reduce the storage life of the late variety, but may cause spotting of the lenticels and severe disfigurement of the apple.

Other emanations of the fruit are important. The apple evolves certain volatile substances which give it the characteristic smell. The exact chemical composition of these substances is not yet known, but there is evidence that a substance, or group of substances, belonging to the heavier fraction of these volatile substances causes the troublesome storage disorder known as superficial scald.

## Control of Scald

In the United States of America, where scald is often a serious factor in the cold-storage of apples, a method of control has been devised — wrapping the individual fruits in a paper impregnated with colorless and odorless mineral oil. It is a general practice in the United Kingdom to wrap apples of susceptible varieties in oil-impregnated paper, but pears may be damaged by oiled wrappers. The wrapping of apples before storage has disadvantages: It takes time, and it costs money. And although frequently apples, even of susceptible varieties, are stored successfully *without* oiled wraps, it is considered a necessary insurance against scald.

Some way to control scald without the use of wraps is needed. Experiments have recently been carried out both in the United States

and the United Kingdom to explore the possibility of using filters charged with activated charcoal through which the atmospheric content of the store may be circulated. So far, experience has indicated that the heavier volatile substances do not reach the filters; they must be removed by an absorbent placed close to the fruit, but not directly on its surface. Mineral oils applied directly to the skin cause severe internal injury by interfering with the exchange of carbon dioxide and oxygen between the inside of the fruit and the outer air.

Gas storage of plums and cherries is not promising. Supernormal concentration of carbon dioxide soon causes severe injury and browning of the flesh.

Strawberries are not injured by 10 percent of carbon dioxide and 11 percent oxygen; but the advantage of gas storage is too small to be practical.

Broccoli and cauliflower react favorably to gas storage. In the United Kingdom a short spell of warm weather sometimes hastens the maturation of broccoli to such an extent that there is a temporary congestion on the market. While cold storage at 0° C. keeps broccoli for three weeks, it is possible to store the vegetable in 10 percent carbon dioxide and 11 percent oxygen for three or six weeks, after which it remains in a marketable condition for four or five days.

Certain conditions must be closely observed when gas storage is used for fruit: It must be picked at the right stage of maturity, and it must be loaded and sealed promptly. To satisfy these conditions, the stores must be situated at the producing end of the distribution link. It is not advisable to gas store at the marketing end. Consequently, in the United Kingdom, the gas storages are mainly on individual farms or at central packing plants where an association of growers can employ expert management.

Fruit is not usually graded and packed before storing. There is not time. It is better to eliminate unsound fruit, wrap, and store in clean orchard boxes. The fruit can be packed after its removal from store and after allowing condensation to dry off the surface.

Wastage of gas-stored apples is exceedingly small — often less than one-half of 1 percent.

## FROZEN FRUITS AND VEGETABLES[7]

The first step in the preparation of fruits and vegetables to be frozen is, of course, the right choice of variety and the determination of the degree of ripeness.

[7]Based on a paper presented by P. Clement.

## *Vegetables*

After the preliminary operations of grading, paring, trimming, husking, and washing, as shown in Figure 61, the vegetables are blanched to destroy the enzymes (catalases, oxidases, peroxidases) which may cause changes in flavor in the frozen product. Blanching is generally done by immersion for a few minutes in boiling water or in steam under ordinary atmospheric pressure, but steam at a pressure of 350 g/cm² also destroys the enzymes and takes half the time required for blanching in boiling water.

The inactivation of the enzymes during blanching can be determined by means of a 10 percent solution of guaiacol in pure alcohol in the presence of hydrogen peroxide. The technique consists in placing 5 g. of tissue in small pieces in a test tube with 5 cm³ of water, and adding 1 cm³ of 10 percent alcoholic guaiacol solution, then 1 cm³ of 0.5 percent hydrogen peroxide solution. After two to five minutes a brown coloration occurs if any peroxidase is present. No coloration is observed if all the peroxidase in the tissues has been destroyed by blanching.

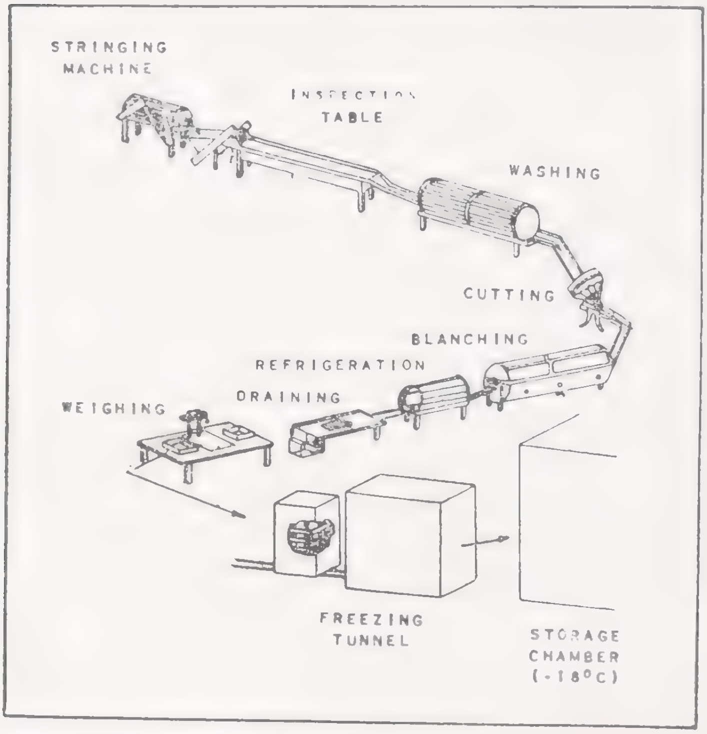



*Figure 61. Flowsheet indicating operations used in preparing and freezing green snap beans.*

Blanching fixes the green coloring matter and nearly sterilizes the product. The disadvantage is that it removes a portion of the nutrient substances, dissolving them out in the water. Blanching has been

tried by infra-red rays, but this method dries out the surface of the product without making its inner enzymes inert. Electronic blanching by dielectric heating has been suggested for some products.

After blanching, the product must be cooled immediately in a minimum of very cold water. Air-cooling prevents the loss of soluble substances such as water-soluble vitamins and sugar, but there is danger of oxidation and dehydration.

### Fruits

Most fruits, with the exception of pears and apples, do not require blanching; but it is necessary to make the enzymes less active. For this purpose, cool sugar syrup is used to cover the fruit before freezing. Dry sugar can also be used; it plasmolyzes the tissues and dissolves in the liquid exuded. The syrup concentration varies from 35 to 60 percent, depending on the type of fruit. The fruits have to be completely covered in order to reduce the risk of oxidation from contact with the air. The addition of an antioxidant to the sugar syrup is recommended for peaches and certain other easily oxidizable fruits. Ascorbic acid in the proportion of 0.05 to 0.50 percent may be used. Some fruits, particularly such as apples, which have passed the right stage of ripeness, are liable to softening after thawing. To prevent this, the fruit may be steeped for five minutes in a dilute solution of calcium chloride acidulated with citric acid to obtain a pH of 2.7 or 2.9. After immersion, the fruit should be rinsed to eliminate the bitter taste of the calcium chloride.

## Specifications

The Inter-occupational Federation for Quick Freezing has formulated, for France, the following specific requirements for quick frozen vegetables and fruits, which will serve as an example:

### Vegetables

Vegetables should be packed either whole or in pieces sufficiently large to be identified. After thawing and cooking, the products should have the appearance, color, consistency, odor, and flavor of freshly cooked vegetables. There should be no waste in their use, and they should be usable in the same culinary preparations as the fresh vegetables. They should have the following specific characteristics:

*Asparagus:* Only the young shoots, peeled or scraped if necessary, should be used: the stalks should be over 15 cm. in length and with a diameter at the base of at least 9 mm. The stalks should be erect, with white, purplish, or light green tips, firm and without mildew.

spots, or bruises. Asparagus is graded according to the base diameter in the fresh state:

| | |
|---|---|
| Giant | over 25 mm. |
| Extra Large | from 19 to 25 mm. |
| Very Large | 14 to 19 mm. |
| Large | 11 to 14 mm. |
| Average | 9 to 11 mm. |

*Asparagus tips:* May be taken from asparagus of any size or from twisted, green or slightly flowering asparagus, if it is sound.

*Celery:* Only the hearts and white parts of the branches should be used. Minimum length is 13 cm.

*Cauliflower:* Should either be whole or in compact pieces. The maximum length of each piece should not exceed 60 mm.

*Spinach:* Should be presented in clumps without yellow leaves, and the leaf stalk cut less than 3 cm. from the leaf blade.

*Snap beans:* Bean varieties without tough inner membrane, washed and trimmed, with the seed formed or not quite formed (extra fine). The proportion of stringy or faulty beans should not exceed 3 percent for extra fine snap beans and 8 percent for snap beans.

*French beans:* The edible pods of certain bean varieties, washed and trimmed. Trade categories are graded according to maximum width of the fresh state: Extra Fine, 6 mm.; Very Fine 7.5 mm. French beans should be tender, of uniform shape, and fresh color. There should be practically no pods with the seed formed. The proportion of stringy or faulty French beans (mildewed, spotted, insect-punctured) should not exceed, for Extra Fine French beans, 3 percent; Very Fine French beans, 8 percent.

*Green peas:* Fresh peas are used, picked while tender and green. The different categories are graded by screening in the fresh state: Extra Fine 7.4 mm. diameter; Very Fine 8.4 mm.; Medium, 9.2 mm. "Sugar peas" are not graded. Green peas should not be flattened and should have a uniform green color. The proportion of faulty peas (deformed, yellow, spotted, brown, sprouted) and extraneous matter should not exceed 5 percent for Extra Fine and Very Fine peas, or 8 percent for Medium grades. For all grades at least 75 percent of the peas should have the cotyledons inside the epidermis. After thawing, green peas should be tender but firm to the touch.

### Fruits

Fruits should be packed whole, in halves, or in quarters, with or without the addition of sugar or syrup. Only crushed or granulated sugar, equivalent to type No. 3 of the Chamber of Commerce of Paris, can be used. The proportion of sugar should not exceed 18 percent of the weight of the fruit treated. The proportion of sugar syrup used should not be more than 30 percent of the weight of the fruit.

and the sugar content of the syrup should be at least 20 percent. Fruits of the same consignment should be of the same variety, size, and color. Immediately after thawing, the pieces should be soft but retain their original shape. When the fruit is in halves or quarters, the sections should be cleanly cut, the color unchanged, the odor and taste agreeable, resembling the fresh fruit as nearly as possible.

*Apricots:* Varieties used should have a firm pulp. The fruit should be cut in two along the natural division and stoned. The minimum diameter for each piece is 35 mm.

*Black currants and gooseberries:* Should be separated from stems.

*Mirabelle plums:* Fruits should be whole, not stoned, measuring at least 20 mm. in diameter.

*Peaches:* Only freestone varieties with firm pulp should be used. The fruits should be peeled, cut along the natural joining into two halves, and stones. The diameter should measure at least 45 mm.

*Pears:* The varieties used should have a firm fine pulp. The fruits should be peeled, cored, carefully trimmed, and cut into two, three, or four sections with a minimum length of 60 mm.

*Greengage and Quetsche plums:* The fruits should be either whole or cut in two and stoned. The minimum diameter is 35 mm. for greengages and 25 mm. for Quetsches.

## Packing Frozen Products

In most cases, the products are packed before freezing; it is often difficult to pack a product solidified by freezing. On the other hand, fresh products such as blanched vegetables or fruits in syrup are easily packed.

Packing beforehand, however, has a definite drawback, since it markedly retards the speed of freezing. Curves of central temperatures were plotted, in relation to time, of two identical lots of vegetables, one in a metal mold and the other in waxed paper. These curves (Figure 62) show that the packaged material takes about two and a half hours longer to freeze. However, the use of metal molds entails unmolding the product, generally done in warm water, and packing after freezing, which seriously complicates the operation.

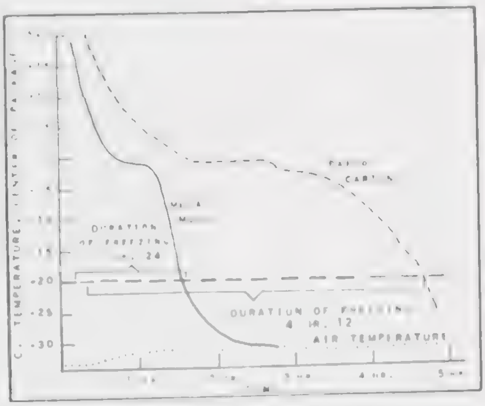



*Figure 62. Comparative rate of freezing of asparagus packed in metallic molds and paraffined paperboard cartons.*

For packing, whether before or after freezing, waxed paper covered inside and out with cellophane is generally used; the sizes have been standardized.

The packs authorized in France have the following dimensions Wholesale packs, 300 by 200 by 50 mm.; Household packs, 150 by 100 by 50 mm.; Half-size packs, 75 by 100 by 50 mm.

Experiments are being made on the use of water- and air-tight receptacles similar to cans, but this type of pack does not seem to find favor with French consumers.

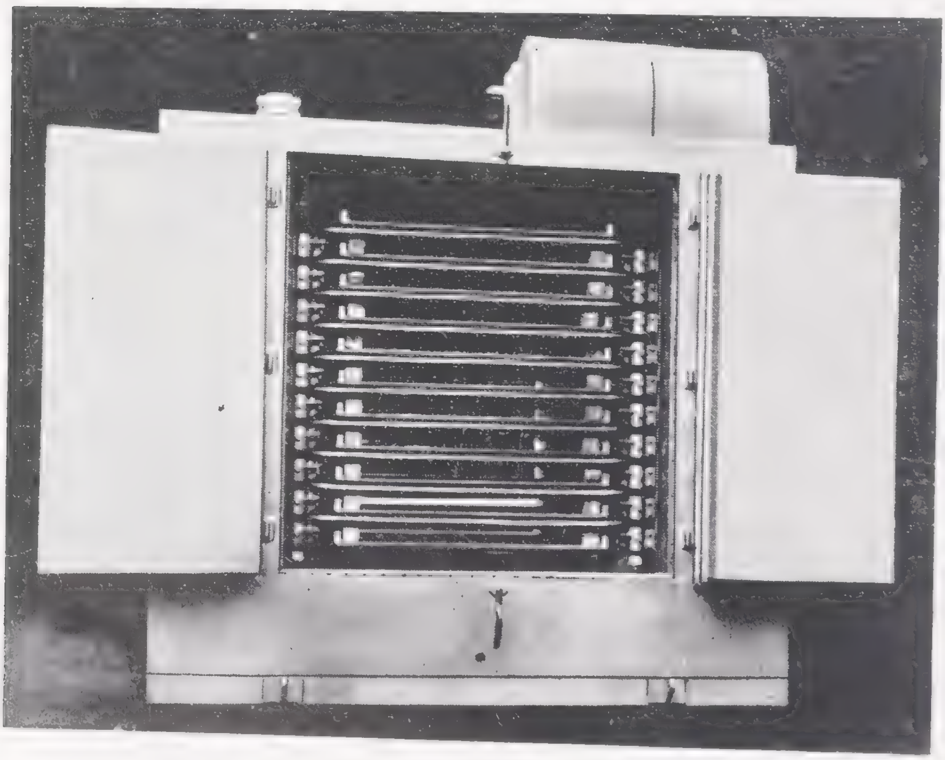
## Freezing Processes

After the products have been properly prepared and packed, they are taken immediately to the freezers and frozen as rapidly as possible. The contact and air-blast systems are used.

In an apparatus of the contact system type, of which the best known is the Birdseye multiplate freezer, the coefficient of transmission is increased by making close contact between the refrigerating agent and the products to be frozen. The products are wedged between hollow metal plates through which cold brine or other refrigerant circulates.

Refrigeration can be done very rapidly with this equipment, but

*Figure 63. Contact freezer used for packaged fruits and vegetables.*



it can be used only intermittently, and only products of the same thickness and of the same parallelepipedal form can be treated. Figure 63 illustrates a contact freezer.

In machines operating on an air-blast system, the air is utilized as the transmission agent between the refrigerating fluid and the product to be frozen. Since air has a very low specific heat, a considerable amount has to be passed over the products. An air velocity of 4 to 6 m/sec. and a temperature of $-30°$ to $-40°$ C. give satisfactory results.

Air-blast freezing machines used in France, for example, are of many types, but all resemble a tunnel: a mechanical system moves the products along at a speed sufficient for them to be fully frozen during their passage through the tunnel. This equipment, therefore, operates on a semi-continuous basis. Figure 64 shows one type of tunnel freezer.

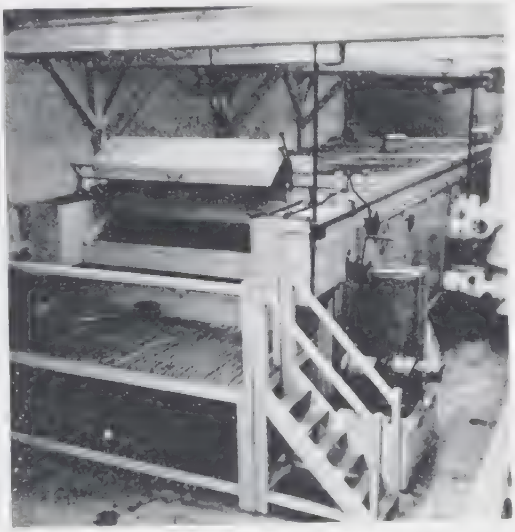


*Figure 64. One type of tunnel used for freezing fruits and vegetables.*

The conveyers usually consist of endless belts on which the packs to be frozen are placed separately. They may also consist of shelves attached together, enabling the simultaneous loading of a certain number of packages. In some cases, in order to prevent the retarding action on freezing of the packing material, the product is frozen in bulk; this is often done in the case of green peas and beans, which are placed directly on the belt. The main advantages of this process, which has been adopted in many plants, are its extreme simplicity and the fact that products of all kinds and all sizes can be treated.

A French designer has perfected a multicellular tunnel consisting of a series of cells, each accommodating a trolley, on which the products to be frozen are arranged in superimposed rows. Particular attention was given to the problem of air circulation, and the temperature remains uniform in all parts of the tunnel.

## Distribution of Refrigerated Products

Experience in France will serve as an example of some of the problems encountered in distributing refrigerated products, and some methods of dealing with these problems.

### *Need for a Refrigerated Chain*

During freezing the temperature of the products should be lowered to about —20° C. for perfect preservation. Good material, proper preparation and freezing are not enough to ensure the products reaching the consumer in excellent condition. The product must be held at a low temperature until it is used. Best results are obtained if the temperature of the frozen product is maintained at —18° to —20° C. during storage, transportation, and display in the retail store.

### *Stages in Distribution*

To ensure that frozen foods are properly handled at all times during storage and distribution, an organization must be setup extending

*Figure 65. Interior of cold storage room in warehouse.*

from the freezing plant to the retail shop. Such a system is called the "refrigeration chain," a name which well expresses the idea of continuity in maintaining uniformly low temperatures.

An actual chain organization now operating in France has 21 freezing plants in the different production zones of France, including five in Brittany, four in the Paris area, one in the Orleans area, one in the Eastern area, eight in the Lyon area, one in the Bordeaux area, two in the Roussillon area, and two in the Vendee area.

The waxed-paper and cellophane-wrapped packages are immediately placed in shipping cases made of corrugated fiberboard of the following interior dimensions: Length 530 mm., width 320 mm., height 220 mm. These cases facilitate handling and sorting, and at the same time reduces the risk of accidental thawing during transport.

The shipping containers are stacked in a cold room at —18° C., which must be large enough to hold the output of at least two or three days' operation. On leaving the freezing plant, the containers are loaded on refrigerated trucks, which take the products of the region to a regional refrigerated warehouse. Here the consignments are arranged according to brand and category.

When seasonal production is finished, the stock is transported by refrigerated cars or trucks to refrigerated warehouses in the large consumption centers. The products are distributed from the large public warehouses to the wholesalers, who utilize small warehouses within their range of operations or special cold rooms, where the temperature is maintained at —18° C. From the wholesaler the products are taken to the retailer in specially equipped light motor trucks and placed in the storage units installed in the retail shops.

These links in the distribution chain are now examined in greater detail.

### Storage

The cold rooms, whether in the freezing plant, the public depot, or at the wholesaler's, are, or should be, maintained at a constant temperature of —18° C. The refrigerating equipment should be of such quality as to guarantee this temperature being maintained. Particular attention should be given to insulation by a layer of cork at least 24 cm. thick. Figure 65 shows the interior of one of these cold rooms maintained at —18° C. in a large public warehouse. To prevent dehydration during storage, the chamber should be slightly ventilated, or a system of direct radiation used. The evaporation temperature of the refrigerant should be as near as possible to the temperature of the room.

There are now some sixty large refrigerated warehouses in France, having a content of approximately 150,000 $m^3$ of cold rooms kept at —18° C.

### *Retail Stores*

On arriving at the retail store, the products are taken from the wholesaler's truck and placed in special units maintained at —18° C. and having a maximum capacity sufficient to store 400 kg. of refrigerated products. The packages are stripped of their corrugated fiberboard covering so they will occupy less space.

The storage equipment in the shops usually consists of a counter 80 cm. high, opening at the top. These counters should be particularly well insulated. The refrigerator equipment consists of an evaporator immersed in a nonfreezing brine in the area between the two walls and the inner tank. The compressor for a 600-liter case has a ¾ h.p. motor.

There are nearly 200 of these refrigerated cases in Paris, and 1,000 in the provinces. The counter is open on top, and the front is fitted with transparent glass, and a mirror slanted at the right angle to show the produce (Figure 66). The temperature of —18° C. is maintained by special evaporators arranged vertically, and the introduction of heat is avoided by a current of cold air which forms a "cold blanket" over the foodstuffs and effectively protects them against any rise in temperature.

Frozen vegetables, unless the consumer's refrigerator has a frozen food compartment at —10° C. or lower, should be cooked promptly after purchase. Refrigerated vegetables are best thawed during cooking. Fruits to be eaten raw should be placed in their cellophane packing in the electric refrigerator where they will thaw out slowly. They should be eaten before they are completely thawed.

### *Trade Organization*

The Fédération interprofessionelle de la congélation ultra-rapide (Inter-professional Federation for Quick Freezing), which was established in France in 1946, includes all packers of frozen products (fruits, vegetables, fish, cooked dishes, etc.) and wholesale importers engaged mainly in importing frozen fish into France from Denmark, Iceland, Norway, Sweden, etc.

The Warehouse-Transport Association is composed of all the large public and private cold-storage warehouses with storerooms maintained at a temperature of —18° C., and with means of rail or road transport at the same temperature.

The Merchants' Association represents all merchants, wholesalers, or retailers owning cold rooms or equipment maintained at a temperature of —18° C. for selling quick-frozen products.

To complete this organization the F.I.C.U.R. includes two other technical groups: The manufacturers of refrigerating equipment required for constructing both the refrigerator plants and the retail stores, and the allied industries comprising the cellophane, dry ice

and paperboard trades, etc.

The F.I.C.U.R. aims chiefly at advancing the quick-frozen products industry and trade by: (1) co-ordinating and supporting the individual efforts of its members; (2) collaborating with the public authorities in order to fix the regulations and to see to their enforcement at every link of the refrigeration chain; (3) undertaking or fostering technical research to further their objectives; (4) employing every possible means of propaganda; and (5) keeping in contact with other countries in order to follow their progress in refrigeration methods.

*Figure 66. Retail display cabinet for frozen foods.*

### Selling the Products

The plants grouped about F.I.C.U.R. have ample refrigeration facilities. Unfortunately, owing to the shortage of distribution equipment, the selling units still lag far behind. This explains why production so far has been voluntarily limited to 2,000 metric tons per year. The F.I.C.U.R., however, is seeking to advance the young quick-freezing industry by improving the distribution network, augmenting temperature-controlled transport, and by increasing the number of retail refrigerator stores. Although French manufacture is still blocked by an inadequate distribution system, foreign markets offer an important outlet. In 1947 France exported 450 metric tons of high-quality frozen fruit. But, in developing this business, French manufacturers must take into account that the tastes of the foreign consumers differ from those in France. In France, for instance, the market demand is almost exclusively for Extra Fine (very small) green peas, whereas in England the demand is for the large Thomas Laxton pea. French producers could supply this type, but unless it is specifically ordered, they hesitate. It would find practically no sale in France. This is also true of black currants, bilberries and mulberries. These fruits are consumed fresh in some countries, but in France they are only utilized in the processing plants, mainly for fruit syrups. France could also further develop the refrigerated products industry with abundant supplies of fruit and vegetables from North Africa.

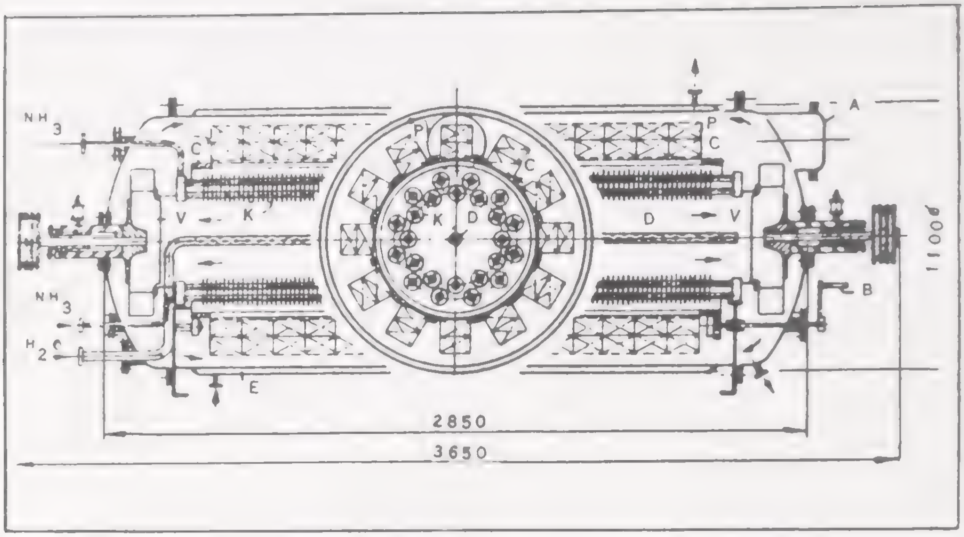



*Figure 67. Diagram of the Helgerud freezing apparatus.*

## The Helgerud Process[8]

The usual treatment of vegetables before freezing includes grading and trimming, washing, heating, cooling, draining, and packing.

Every preserving method aims at careful treatment of food. As improvements are made, a constant and gradual endeavor must be made to use them so that the processed foods retain their original properties and nutritive value.

The disadvantages of the customary methods of preparing vegetables for freezing can be summed up as follows:

1. By heating to a high temperature, damage can be done, particularly by oxidation.

2. By subsequent washing and cooling in water, a part of the water-soluble vitamins, taste, and aroma are lost.

3. The treating process requires considerable energy consumption because the blanching heat is lost in the cooling water.

The difficulties seem to be solved by the patented apparatus for pretreating and freezing berries and vegetables, which has been constructed by Chief Engineer Civind Helgerud, A/S Kvaerner Brug, Oslo, Norway.

A diagram of the new apparatus is shown in Figure 67. It consists of a cylindrical container with one opening, A. The container has a water jacket, E. In the axis of the container a cooling element K is placed, and two ventilators are fitted in the end pieces. The container has an inlet for steam, and an outlet for condensed water. The element is connected to a suction and pressure pipe for ammonia; the container is also connected to an air-pressure pipe.

[8]Based on a paper presented by O. Sjetne.

The foods to be frozen are placed in the cylindrical container, which can be gradually turned as the apparatus is filled, by means of toothed gear connected to the crank, B. The treating process is as follows: The raw vegetables to be treated are trimmed, washed, and graded. They are placed in perforated waxed boxes, which are placed in baskets inside the apparatus. Two sides of the baskets are perforated similar to the carton. After the apparatus is filled, heat is applied to the vegetables by opening the steam inlet near the perforated central pipe, D. The air in the container is blown out and the steam, which flows in through the holes in the boxes, condenses on the foods and heats them to the blanching temperature.

When blanching is completed, the steam inlet is close and the container lid, A, is tightened. Cooling water is let into the jacket, E. The steam in the container condenses on the outer walls and a vacuum is formed. In the meantime the condensation, which has settled on the foods during the blanching, boils and takes the heat of evaporation from the foods. The products are thereby cooled down to a temperature corresponding with the steam's saturated temperature at the pressure prevailing in the container.

After cooling, air or gas is let into the container and the condensation from the cooling process is drawn out through the pipe, F, in the bottom of the container. Thereafter the water drain cock and cooling water supply are closed and the water in the cooling jacket is drawn off, while compressed air or compressed gas is let into the container.

The fans, V, and the cooling machine are started. The cooling machine draws the ammonia from the evaporation tubes, K. The inlet and outlet for ammonia gas from the container are shown by arrows. The fans draw the air from the central section of the container, force it through the packages containing the foods and over the cooling element back to the central section of the container. During this process the air is cooled by the cooling element and the foods are cooled and frozen.

When the foods are cooled to the desired temperature, the compressed air or gas is removed and the lid, A, is reopened and the baskets are taken out. The ammonia suction pipe is closed and the ammonia fluid pipe opened, new baskets are inserted, the steam is turned on, the cooling element is defrosted, the ammonia fluid is forced by the high temperature over into the receiver, and the blanching process begans again.

Figure 68 shows a test erection of the apparatus during the experiments.

Engineer Lydersen, who has charge of this pilot plant, has carried out an experiment with the apparatus based on temperature measurements in the apparatus and in the foods. The measurements are

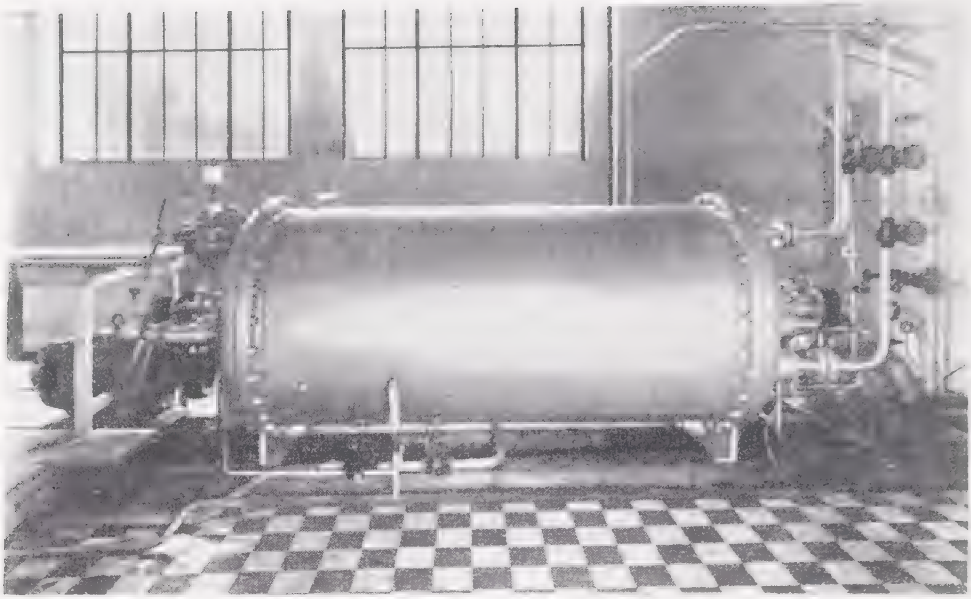


*Figure 68. The Helgerud apparatus.*

taken with thermo-electric elements placed inside the foods, and the course of the temperature is shown in Figure 69. The figure diagrams the whole process, including blanching, vacuum cooling, and pressure freezing. The treatment starts at a temperature of +20° C. when the steam is turned on. Within five minutes the temperature rises to +80° C. and the blanching takes place within four minutes up to +96° C. After eight minutes the container is closed and the cooling water is let into the cooling jacket. Within four minutes the temperature drops to +30° C. At this point cooling is interrupted, the condensate is blown out, the freezing machine is set in operation, and the air pressure is increased in the container. Within the next ten minutes the temperature is brought down to 0° C., and 45 minutes from the beginning the foods are at a temperature of —4° C. After 50 minutes the temperature is —11° C. Experiments have been carried out on the freezing of cauliflower. The cauliflower was cut into pieces of approximately 30 g. each. The test apparatus has a capacity of 180 kg. Considering the time necessary to take out foods and refill the apparatus, it has a capacity of 1,440 kg. per eight hour working day. The advantage of this apparatus, confirmed by experiments, can be summed up as follows:

The foods are cooled without access of air and destruction by oxidation.

In the course of cooling, pure, clean water evaporates directly from the foods, so that the aroma, substance, and vitamins are retained and not washed away. The State Domestic Science Research Institute carried out experiments on the content of ascorbic acid with parallel

tests on cauliflower frozen in the usual way by cooling in water and treated according to the new method. The following results were obtained: The samples were taken after two months' storage and analyzed. Cooked for serving, samples cooled in running water showed 26 mg. of ascorbic acid to 100 g. of food as an average of 24 samples. Samples according to the new method showed 31.2 mg/100 g. for an average of 24 samples. The cooking water's content of ascorbic acid was respectively 5.9 mg/100 g. and 3.9 mg/100 g. of the cauliflower. Further, it appeared that cauliflower frozen in the usual way lost 8 percent of its weight during cooking, while cauliflower frozen according to the new method absorbed 2 percent water. Upon subjective testing of the color, taste, and consistency, the cauliflower frozen by washing with water showed a less favorable result than that frozen according to the new method. The taste and aroma, particularly, were stronger in the sample frozen by the Helgerud apparatus.

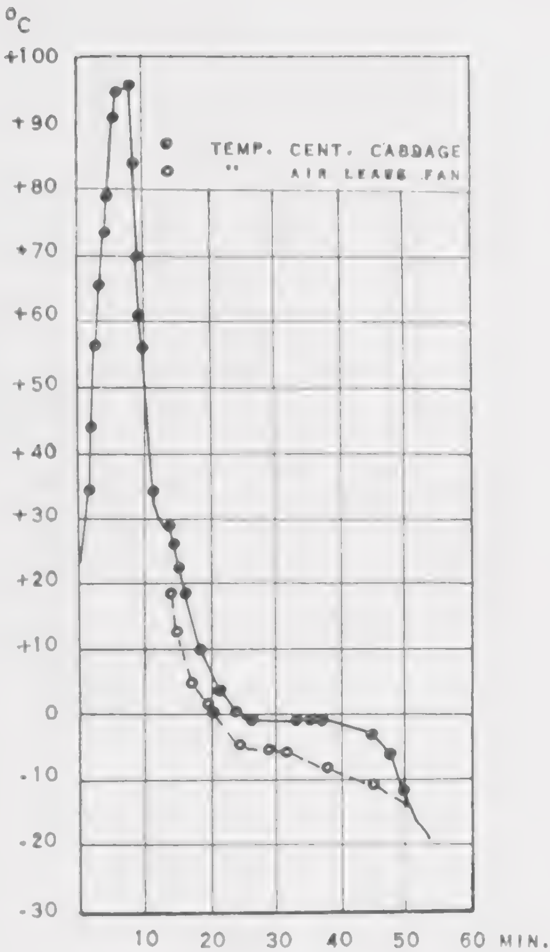



*Figure 69. Course of temperature of vegetable undergoing blanching, cooling, and freezing by the Helgerud process.*

The surplus water condensed on the surface of the foods evaporates during the cooling, so that the foods regain their fresh, shiny appearance. This is of importance for subsequent freezing, since fresh water gives the foods a dull and grey appearance.

Since cooling takes place so quickly and under vacuum, the foods during cooling are not exposed to changes, either from the surroundings or the cooling medium.

By means of the condenser, a total heat gain is made possible in the cooling water, for the entire heat of condensation is absorbed in it.

The process saves labor, for it is not necessary to move the foods.

Waste water, sea water, or that from the cooling plant's condenser can be used for cooling. It is not necessary to purify or sterilize this water, for it does not come in contact with the foods.

The foods are already packed, there is no opportunity of reinfection upon withdrawal from the blancher and during packing. All three steps are accomplished without the foods being touched by hand, and without the boxes being moved.

For freezing of small vegetables, such as peas and beans, the practical form of the apparatus can be changed, so the foods can be treated without packing. The foods will thus leave the apparatus in a frozen state and can go direct to packing machines equipped with insulated containers. The same procedure can be employed for freezing berries without the addition of sugar — for example, blueberries, red currants, and cranberries. For berries to be frozen in syrup, it is possible to freeze the berries beforehand under gas pressure and then, during packing, add syrup cooled to the freezing point of the goods.

There are divided opinions about the importance of the speed of freezing on the quality of the processed foods. Apart from this, it is an enormous advantage in the wholesale production of frozen foods that the process can be done quickly. The freezing speed of the Helgerud apparatus has also been measured and compared with the calculated freezing speed of other methods using similar sized packings and the same evaporation temperature. The results (Figure 70) show that:

1. By freezing in still air the freezing time is 8.25 hours;

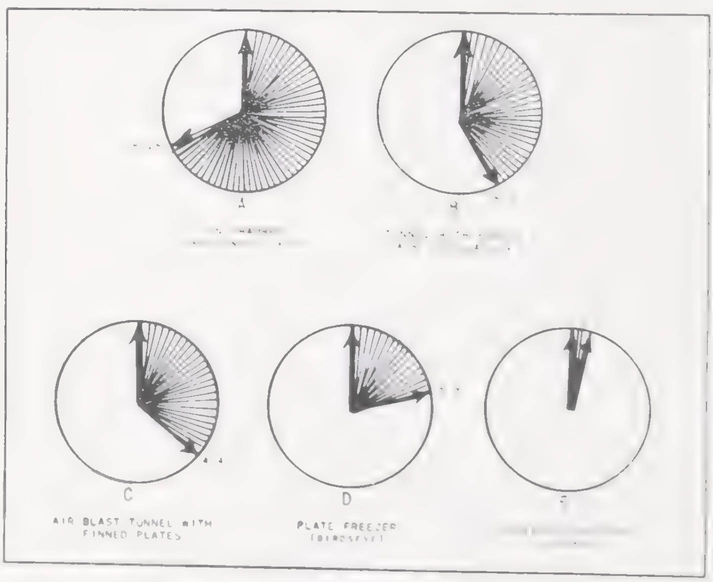



*Figure 70. Freezing rates by various methods. (Chiefly from data by R. Plank)*

2. By freezing in tunnels with circulating air the freezing time is 5.1 hours;
3. By freezing in air tunnel with rib plates the freezing time is 4.1 hours;
4. By freezing in Birdseye type contact freezer the freezing time is 2.7 hours;
5. By pressure-freezing by Helgerud's method the freezing time is 0.5 hours.

## MEAT AND MEAT PRODUCTS[9]

### Fresh Meat

The first principle in the handling of meat is that, directly after slaughter of the animal, the carcass should be kept under such conditions as to minimize damage by bacterial action. Since bacterial action depends on the temperature of the meat, the more rapid the cooling, the longer period during which the meat is fit for human consumption. Butchers, throughout the world, therefore, choose well-ventilated houses for cooling their meat, which permits natural air currents to pass over and cool it.

Conditions of cooling vary with climatic conditions, and in countries with a high humidity and high temperature, meat has to be consumed promptly. But it is rapidly becoming known throughout the world that even though meat is consumed locally, artificial cooling is well worthwhile. Artificial cooling may be nothing more than air conditioning to overcome variations in natural conditions. Meat for local consumption or for consumption after short hauls is usually not intended to be kept longer than 48 hours. This is the time necessary to permit it to pass through the phase of rigor mortis, which allows the meat to set sufficiently for cutting without "slip." Low temperatures are not necessary and may be undesirable because of the risk of damage from condensation on the meat when leaving the cooling rooms for distribution, or while hanging in the markets or shops.

Fresh meat produced in one center for distribution to a community at some not too distant point should have what amounts to air-conditioning, maintained during transit to retain the food value and palatability of the product. A typical example is the production of meat in the center and west of the United States for consumption in the western states; in this trade the meat is cooled to about 0° C. at the producing centers and is kept during transit within a range

[9]Based on a paper presented by J. A. Brewster.

of temperature 0° to 5° C. At the distribution center it is placed in cooled salesrooms, where the air is conditioned by refrigeration.

### *Chilled Meat*

Chilled meat, as it is generally understood in England, is meat kept at temperatures at or slightly below the freezing point long enough for transportation to the center of distribution. The meat is preserved by keeping it at a low enough temperature to retard the effects of bacterial action, compared with frozen meat, which can be stored more or less indefinitely at temperatures causing harmful bacteria to become dormant. The production of chilled meat requires very special care. Any contamination during production becomes vastly multiplied in storage and transport and can have disastrous effects on the product. The animal must be clean when it enters the slaughter floor; equipment and tools must be sterilized; the air must be constantly examined for bacteria and mold spores; the water used, the drying cloths, the wrappers, and the clothing of men handling the meat must be clean; walls and floors of coolers where the meat is first treated must come under constant and careful examination; brine sprays and cooling apparatus must be sanitary both at the point of production and during transport. Most of these matters are relatively simple, but they require constant supervision and imagination in tracking down possible sources of infection.

The coarser fibers of beef, as compared with mutton or lamb, or even pork, show a very real advantage of chilling over freezing, which is not shown in chilled as against frozen meats of the other species.

For chilling beef, the lower the temperature the better preservation, but the shorter is the time before ice crystals begin to form in the meat. A balance must be struck, therefore, between temperature and marketing factors. Before the war, chilled beef was carried from South America or Australasia. The time required in transit made it difficult and exceptional to transport to England chilled beef which had not the least trace of ice crystals, which spoiled the appearance and palatability of the meat. The meat was transported almost entirely in the holds of ships, which were cooled by the circulation of calcium chloride brine in pipes in the ceiling and on the sides of the holds. The circulation of air was by convection, and, as the temperature of the meat reached its freezing point, the circulation would become sluggish. Since the condition of the air in these holds depended upon its passing around the pipes containing the refrigerant, the dew point rose to a dangerous level, particularly towards the end of the voyage when there was a heavy coating of frost on the cooling pipes. Under certain conditions, there might even be thawing of the brine pipes, with a resultant condition of humidity favorable to the growth of mold spores and bacteria. These condi-

tions were counteracted as far as possible, but a lot depended on the skill of the engineers in charge, and on their ability to maintain a full flow of brine in the pipes at as high a temperature as possible. The meat could not be put on board at a high temperature because this might have overloaded the cooling pipes in the holds with moisture. It was found to be essential in the initial stages of preparation in the factories to bring the temperature down as quickly as possible without causing any surface freezing.

At the same time, it was not possible to allow the cooling-room temperature to drop below the eventual carrying temperature on ships. The cooling rooms were, therefore, built with ample height, and arrangements were made for cooling by a rapid convection current, or designed for circulation of cool air by fans.

The normal carrying temperature for chilled beef in holds cooled by brine grids was —1.4° C.; at this temperature, and with the slow convection current in the type of hold used, the meat began to freeze in about 18 to 21 days; by 28 to 32 days it was usually semifrozen. The freezing point of beef varies around —0.8° C., so there was only a small margin for the production of convection currents. A critical period was gone through when the latent heat of the meat was dispersed and the surface temperature began to drop below its freezing point, particularly if there was little work to be done by the brine pipes to eliminate heat leakage into the holds. Various control methods have been tried, and meat has been successfully carried at temperatures around its freezing point, eliminating freezing during the course of the normal voyage; these methods included drying the air in the holds by simple processes, for instance, by the use of calcium chloride or electric heat, raising the temperature of the meat itself to permit a more active circulation by convection, and better air conditioning to increase heat removal by the brine pipes.

Most recently built ships are designed to carry chilled beef, fruits, and other produce in the same type of hold. These ships use small batteries of brine pipes to cool the air, which is circulated by fans around the sides of the hold and down through the ceiling. Return ducts are arranged so that the entry and return ducts cover the sides of the holds, protecting the cargo heat leakage and unequal insulation. While this system, due to the reduced pipe area and forced flow of air, increases the shrinkage on shipboard, a matter of commercial consideration, meat free from ice crystals and in generally better condition more than compensates for the difference.

There is still, however, the factor of loss of bloom and change in flavor, particularly in fats. These changes in chilled beef correspond to the staleness affecting frozen meats, depending on the temperature at which they have been kept, within 3 to 12 months. There is a definite change in chilled meats in 34 to 36 days after slaughter (40 days is the limit for satisfactory carrying of chilled meat).

To prevent mold growth during the storage and transportation of chilled meats, the sterilamp has been used, mostly for the partial prevention of bacterial growth during the holding of meats at relatively high temperatures for rapid aging or "tenderizing." The use of small concentrations of carbon dioxide in the transportation of chilled meat from Australia and New Zealand is a common practice as a mold growth inhibitor.

## *Bulk-frozen Meat*

The handling of frozen meats in bulk presents problems of a different nature. The same principles of hygiene are necessary as in the handling of chilled beef, but the results of neglect are not so disastrous. The problem before the war was mainly to maintain meat of a fresh, bright appearance. The most important factor was rapid cooling at low temperatures. However, it did cause a little extra shrinkage in the initial stages of preparation. Subsequent storage conditions and temperatures also have their effect, and considerable damage can be done to the appearance of carcasses by neglect of proper precautions in loading and unloading, and in transit between ships and stores.

During World War II the main problem was to make the best use of the available refrigerated space, both in transit and in the available cold stores. To this end sheep and lambs were cut in half, and each half tied to the other to save space during storage. The beef was boned out, molded, and frozen. This type of package required new arrangements for freezing, which presented difficulties: there was risk of decomposition inside the meat before it was frozen, which did not exist when the carcass was extended on its framework of bones; this permitted easier heat removal than was possible with the thicker package of boneless meat. A technique was evolved of molding the meat before it was set, doing freezing in hours that had previously taken days.

The method that shows the greatest saving in space, both in production and storage, is the one used in the Antarctic for freezing whale meat. It became evident that any of the known types of apparatus for dealing with products to be frozen in a regular shape would not be satisfactory. It was impossible to make an apparatus that would fit this meat satisfactorily, so it was decided to make the meat fit a mold instead of fitting a mold to the meat. For boned beef, which was handled the same way, a mold had to be made which would take care of the varying sizes of quarters. Working on this basis, a wedge-shaped mold was produced for hindquarters of beef measuring: top, 23$1/4$ by 5$1/2$ in. (59 by 13 cm.); bottom, 20 by 4 in. (50 by 10.16 cm.); length over-all, 5 ft. 1 in. (1.77m.); length up to flange,

4 ft. 10¼ in. (1.5 m.); external dimensions of top including flange, 26½ by 8¾ in. (67.3 by 22.2 cm.). After experimenting to find some of the characteristics of a boneless quarter of hot meat, a method had to be devised of getting the meat into the mold — drawing it into the mold by a vacuum applied at the lower end.

Since this work was carried out in wartime with the scarcity of all classes of metal, it was essential to have rapid freezing so that a large amount of meat could be frozen in a few molds. For this reason the brine bath with circulating brine was discarded in favor of a brine spray directly on the molds, breaking up the brine into a fine spray to get the maximum rate of heat removal from the mold.

The plant, constructed to hold the molds and sprays, was a simple one of wooden racks open at one end with molds resting on the wooden racks. Flanges were provided at the top of the molds, which were slid into the racks by an overhead electric conveyer that picked them up from a truck, filling each rack in turn. The filling apparatus consisted of chutes down which the meat was sent from the boning-room, passing through a movable funnel into the mold on the trucks below the funnel.

The discharge of the meat was simple: Each mold was sprayed with warm water-compressed air, admitted through the same pipe as had been used for vacuum for charging. An electric hoist lifted the quarter from the mold, depositing it for removal to cold storage.

The freezing plant and the temperatures and pressures used saved time and space, as compared with other systems of freezing. An installation with racks for 600 molds, which could be brine-sprayed at one time, complete with overhead conveyers for transporting the molds, was placed in a beef chill room formerly used to chill 120 beef carcasses, which could be reduced to the required temperature for shipping in approximately eight days. The mold freezing plant gave the same heat elimination from 600 molded quarters of 150 beef carcasses in approximately seven hours.

The time taken to freeze slab beef varies from six to seven and one-half hours, depending principally on the size of the quarters. Removal of the meat from the molds takes place when the highest temperature at the interior of the thickest end of the mold is at —1.6° C., the outside temperature being between —19° and —17.5° C. Heat removal is practically complete, but, before stacking, the temperature of the slabs is permitted to equalize, the interior temperature falling and the outside temperature rising. This was done in storerooms at a temperature of approximately —11° to —12° C.

Other methods were used, but in all cases, to get a rapid transfer of heat and to mold the meat to save stowage space, metal contact was used with the molded meat. The molds were either placed on direct expansion pipes or exposed to forced circulation of cold air

## *Freezing Meat Cuts*

Thus far, only the freezing of meat in carcasses or in quarters has been considered. Freezing cuts of meat presents another problem. A well known process of freezing in bags of latex or Pliofilm collapsed in a vacuum can be applied to cuts of beef, mutton, or pork. The freezing of the thicker and heavier cuts of beef or of poultry, presents another problem. Experiments show that there are great commercial possibilities in this if cuts can be produced and are so frozen as to have an appearance and quality at least as good as that of chilled beef.

If a compact plant is required, without the expense of powerful air blasts, freezing in close contact with metal or directly with the refrigerant is essential; this can only be done when the meat is handled while it is still sufficiently pliable, before rigor mortis has advanced too far. The molding of meat in contact with metal, carried out under these conditions and frozen rapidly enough, gives quarters of beef characteristics of quick-frozen meat, which hitherto it had been believed could only be obtained by passing through the critical stage in less than 30 minutes. This means that large pieces of meat can be frozen rapidly and economically, molded to shape, and later cut into packages for distribution. There has been little development of this technique, which can fit in admirably with the increased volume of packaged meats being sold in self-service stores.

## *CHILLED AND FROZEN POULTRY*[10]

The material presented in the first sections of this portion of Chapter 10 is based largely on experience in the United States of America. It will serve to illustrate the basic principles involved in the chilling and freezing of poultry. Experience in Denmark is summarized in the final sections.

## *Cold-storage Poultry*

The importance of this aspect of the refrigerated food industry may be illustrated by the fact that approximately 1,000 million head of chickens are produced in the United States of America each year. About 500 million pounds (226.8 million kg.) of this product is frozen.

Years ago, frozen poultry was considered inferior to fresh poultry. Poultry which had been killed some time previously and then stored, even at a low temperature, slowly took on a "cold-storage

[10]Based on a paper presented by D. K. Tressler.

flavor." The longer the product was stored, the more pronounced was the flavor. Eventually, the poultry became slightly rancid, and later very rancid. It was a common practice 30 years ago, and perhaps even 20 years ago, for butchers selling poultry to sell fresh poultry during the season, then buy frozen poultry in the off-season, thaw it (usually by immersion in tanks of running cold water), and sell it to the unsuspecting housewife as fresh poultry.

Thirty years ago, when storage temperatures for poultry were running around —15° to —18° C., poultry had this definite off-taste. Some of the lawmakers knew that representing frozen poultry as fresh was a bad practice, but they did not stop it. However, they usually made the butcher or grocer who sold thawed poultry put up a sign: "Cold Storage Goods Sold Here."

Today the situation has changed considerably. Some cold-storage poultry has a "cold storage taste," but, for the most part, it is so good after it is cooked that it can hardly be distinguished from freshly killed birds.

## Chilled Poultry

There is not much difference between chilled poultry and the so-called freshly killed poultry. Both are chilled, but "chilled" poultry is usually cooled at a central plant where refrigeration methods are better. Sometimes, live birds are sent to market, killed by the grocer or butcher, and sold without removal of feathers as freshly killed poultry.

Chilled poultry is highly perishable. Even if quickly chilled to a temperature of 0° C., it is next to impossible to keep a freshly killed product for longer than seven days. After that, there is the danger of bacterial growth, which is usually discernible either by an objectionable odor or by the development of peculiar colors around the vent and various other parts of the carcass.

Poultry is killed and handled in pretty much the same way, regardless of whether it is to be chilled or frozen. Chilled poultry is customarily handled either as ice-packed stock or box-packed stock. Ice-packed stock is handled like fresh fish, except that in the United States the poultry is packed into barrels in layers. Each layer of poultry is covered with a few shovelsful of ice and the top is covered with ice. For box-packed stock, the product is chilled in boxes, and kept in a cool room at about —1° C. until marketed. It is believed that the box-packed product not packed in ice keeps somewhat longer than that packed with ice, because ice keeps the surface wet and bacteria thrive better on a moist surface than on a nearly dry surface. Chilled poultry is seldom eviscerated before sale. After chilling, it is transported under refrigeration directly to the retail market and kept in the market cooler until sold.

## *Preparation for Freezing*

In many United States plants for example, the procedure of killing, slack scalding, and plucking is not much different from that commonly practiced in Denmark. The system of moving the carcasses from one part of the plant to another is also substantially the same. However, in the United States, there are at least three systems for killing the birds, scalding them, and removing the feathers.

For killing, there is now a more or less automatic system. The operator hangs the bird on a shackle, which is conveyed through the killing and knifing machine. The head of the bird is subjected to a high voltage electric shock, then a high speed rotary knife cuts through the veins and arteries of the neck, causing rapid bleeding. This process is used in some of the most modern automatic plants in the country. Two other processes are used, in one of which only the veins of the neck are cut by inserting a knife in the bird's mouth; in the other the knife is thrust through the mouth into the brain, and, as the knife is removed, an artery is cut. Thrusting the knife into the brain is necessary in the dry-picking method. In dry-picking, the feathers can be pulled out without scalding, provided the plucking of the bird is started at the instant of killing. By this process the bird passes immediately after the knife thrust to a second operator, who immediately pulls off all the larger feathers. At that moment, when the bird is still warm and the brain tissue has been destroyed, the feathers can be pulled out very easily.

The slack-scalding system is used in the United States more than any other. The temperature of the water must be exactly right — 52° to 54° C. — and the bird should be immersed for not less than 20 seconds and not more than one minute.

Various types of picking or plucking machines are used to remove the feathers. Machines used pick off a high proportion of the feathers by the slapping of fingers and the use of rubber suction cups.

In the United States, locker operators kill and pick poultry. In smaller locker plants, one small picking machine does the whole operation. In the larger plants, more complicated machines are used.

The wax picking method may be briefly described as follows: After the larger feathers have been removed, birds that have been semi-scalded are dried and dipped into a wax bath. The wax is largely paraffin, with other ingredients to give it the desired characteristics. Since the bird is relatively cool, the wax solidifies quickly on its skin. The bird goes a few feet down the line while the wax sets. Then it is cracked and stripped off, pulling with it the hairs, feathers, and practically all the pin feathers. Such an operation eliminates a great deal of the work of plucking. At certain seasons, when poultry has a considerable number of small feathers, the use of this system saves a great deal of labor. The disadvantage is the cost of the paraffin.

but it can be used over and over. After use, the wax and feathers are warmed, the wax is drained off and filtered to remove dirt and very fine pin feathers. With clarifications, the paraffin can be used almost indefinitely. When the waxing is not used, the birds are usually singed after picking.

The next operation is chilling. This is done by hanging the birds on a rack, which is then pushed into a room maintained at about —1° C.

In some plants polutry is packed and frozen without previous chilling. It was formerly believed to be absolutely necessary to chill the birds before packaging. Otherwise, it was thought that if the birds were eviscerated and packed into containers while warm, they might spoil before freezing. It is probable that this idea arose from the practice of packing the birds into wooden boxes, putting anywhere from 12 to 24 in a single box. If warm poultry is packed in a wooden box and then stacked up to freeze, even if a low temperature is used, the entrails are likely to spoil before the birds are frozen. Today, some of the plants immediately cut up the birds to be disjointed, or package individual carcasses and put them in to freeze, completely eliminating the chilling process. This works quite well with lean birds, but with fat chickens, ducks, or geese the hands of the packer become greasy and grease is smeared over the wrapper or carton. It has been found that a bird can be frozen in less time and a better quality obtained if the chill room is eliminated and the products are packaged and frozen individually. It is perhaps the best way of producing a product with a low bacterial count, and a high quality which will stand up for a long time in the freezer.

Many plants in the United States do not eviscerate the birds, but pack them in paper-lined wooden boxes.

## Freezing

Instead of stacking the boxes solidly for freezing, it is best to allow large spaces between them so the air can circulate around each box to speed up freezing. However, if birds are packed 13.5 kg. or more to a single box, it is obvious that no matter how they are frozen a truly quick frozen product will not be obtained because of the mass being frozen.

In 1930, when Clarence Birdseye started to popularize frozen foods, he believed that the housewife would buy frozen poultry if she was assured of high quality. He selected only the best birds and eviscerated them, leaving no blood inside and no feathers outside. He wrapped the giblets (liver, heart, and gizzard) in moisture-proof cellophane or paper and placed them in the abdominal cavity of the bird. Roasting chickens were wrapped in moisture-proof cellophane

and a stockinet slipped over them. Housewives found that chicken packed in this way and quickly frozen in multiplate freezers were excellent.

### *Storage Temperatures*

Storage temperatures used for frozen poultry should be low if poultry is to be kept for any considerable period of time. Even though it is probable that the poultry is to be sold within three months, it is wise to hold it at a low temperature. If three months pass and the poultry is not sold, it can be held longer. And, if it is sold to someone else and he holds it, the product will still be good.

What is meant by low temperature? A survey made in 1936 of storage temperatures used in United States cold-storage warehouses for poultry indicates that the storage temperatures commonly used for poultry were some place between a maximum of —23° C. and a minimum of —32° C. Practically no poultry was stored at a temperature as high as —18° C. As long ago as 1936, it was realized that if poultry is to be held for six months or longer, it must be kept at a very low temperature. As a rule, poultry is killed and frozen in August, September, and October, and is put into storage for an indefinite period. Some of it is moved in November, some in December, some as late as May, so it is better to store at a temperature that will keep it in excellent condition for its maximum storage life.

### *Packaging*

The Birdseye system of packing in use in 1930 is described above. Much of the eviscerated poultry is still individually packed in this way. About 1939 the Cry-O-Vac process was introduced, using a rubber latex bag in which the bird was inserted and a tube put into the neck of the bag. A vacuum was drawn and simultaneously the bag was placed in a current of warm air, causing the latex bag to contract tightly against the skin of the bird. This process was used until after the war began. Then no rubber latex was available, and moisture-proof cellophane was again used. Today, Pliofilm and other plastic materials are being used to accomplish the same purpose as the rubber latex. In general, if poultry is properly packaged at a low temperature it keeps for a very considerable length of time. If the surface flesh of the bird is kept from contact with the air, thus slowing up oxidation, rancidity is greatly retarded.

In general, then, two things must be done in order to prevent the development of rancidity and "cold storage taste." 1. Package properly to prevent desiccation, loss of flavor, and oxidation. 2. Keep the packaged product at a low temperature.

There are different ways of packaging poultry other than putting

the whole bird into a bag or wrapping in moisture-proof sheeting. A great deal of poultry in the United States is disjointed and packed in cartons before freezing. Perhaps such a product would be accepted in Europe, if the idea were tried.

### Broilers

Frozen poultry constitutes a substantial proportion of the frozen food being sold in the United States today. Roasting chickens and fryers are popular, and there is also a great business in broilers—small chickens of about 1½ to 2 lb. (0.68 to 0.91 kg.) each, live weight. They are fed so that they grow rapidly, and the flesh is very tender. They are marketed frozen, split in two down the backbone, but the two halves are put back together. The giblets are wrapped in moisture-proof paper and placed in the abdominal cavity. Then the broiler is wrapped in a moisture-proof wrapper, put in a stockinet and frozen. Cooking is done rapidly under open gas flames or with electric heat directly above the chicken. The surprising thing is that broilers commonly sell on a weight basis at a price considerably under roasting chicken.

### Storage Changes

Some research work on conditions of packaging and storing of poultry so as to obtain a product of the highest possible quality and to determine probable factors in the deterioration of frozen poultry was carried out at the New York State Agricultural Experiment Station in 1940.* Here are some of the conclusions:

> The results indicate that changes of flavor of the flesh parallel to some extent the flavor of the fat. They also show that the kind of wrapping material employed has an influence on the keeping quality of the product. Flavor changes were noted sooner in the chickens packaged in the waxed paper (the so-called locker paper) which had a high moisture-vapor-transmission rate, than in those packaged in more moisture-vapor-proof materials. The chickens wrapped in waxed paper, then stored at —12°C. lost 10.7 percent of their weight (moisture) in six months. Losses from chickens packaged in waxed paper and stored at —18° C. amounted to 4.7 percent in 12 months and 6.4 percent in 20 months. Losses from chickens packaged in a specially coated sulfite paper were 1.5 and 2.4 percent at —18° C. in 12 and 20

*DuBois, C. W., Tressler, D. K., and Fenton, F. The effect of rate of freezing and temperature on the quality of frozen poultry. Refrig. Engineer. 44: 93-99. 1942.

months respectively. Losses from chickens packaged in moisture-vapor-proof viscose sheets and in rubber latex were slight at all temperatures.

It was noted that the undrawn birds lost less weight than drawn birds packaged in the same way. This may be explained by the greater exposed surface in the drawn birds.

In Table No. 10 are indicated the storage periods before rancidity was noted in the fat of the poultry. From these data, it appears that the interior chicken fat becomes rancid in five months' storage at —9° C. and at —12° C. At —18° C. chicken fat shows signs of rancidity in ten months, and at —22° C. there is some tendency toward rancidity in

TABLE 10.—RESULTS OF TESTS FOR RANCIDITY OF THE FAT OF CHICKENS HELD AT VARIOUS STORAGE TEMPERATURES

| Test | Storage temperature | Incipient rancidity noted | Definite rancidity |
|---|---|---|---|
| | (. . °C. . . ) | ( . . . . Months | . . . . ) |
| Active oxygen | — 9 | 2 | 3 |
| Organoleptic | — 9 | 2 | 3 |
| Active oxygen | —12 | 4 | 5 |
| Organoleptic | —12 | 4 | 5 |
| Active oxygen | —18 | 10 | < 12 |
| Organoleptic | —18 | 10 | > 12 |
| Active oxygen | —22 | 18 | > 20 |
| Organoleptic | —22 | 19 | > 20 |

18 months. In making these examinations, it was found that the fat in the cavity of the drawn bird turned rancid sooner than the external fat. The quality of the internal fat was, therefore, used as the criterion, since this fat seems to affect the flavor of the whole chicken when it is cooked. The rancidity tests indicated that the drawn chicken developed rancidity in the cavity sooner than the undrawn bird. However, it will be remembered that drawn birds received a somewhat higher palatability rating than the undrawn one. Perhaps a solution to the problem is to eviscerate the poultry, package in moisture-vapor-proof materials, and then store them at a sufficiently low temperature.

## *Chilling and Freezing Poultry in Denmark*[11]

Before 1932 Denmark imported a fair amount of killed poultry from various countries. At that time, the greater part of the production for killing was old hens and cockerels as by products, when a great stock of young egg-layers were maintained.

The bulk of the killed poultry was consumed by more than 300,000 poultry breeders in Denmark, but, since it was mainly a by-product of egg-production, the killings were, to a great extent seasonal. There was a chicken season in June, July, and August, when most of the two- or three-month-old cockerels were killed, and a hen season in September and October, when most of the hens were replaced. Consequently, in these seasons large quantities of killed poultry were offered for sale at low prices, whereas in other seasons poultry was scarce.

Most of the poultry was killed by the farmers themselves, or by small wholesale buyers, and for sale immediately after killing at the prices then obtainable. It is evident that much seasonal fluctuations offered good possibilities for economic advantage through preservation of the poultry for sale when it was more scarce. However, since the freshly killed poultry was purchased by a great number of small wholesale buyers, who promptly resold it to retail dealers, little or none was frozen and put into cold storage.

Rapidly increasing egg production and the desire to replace layers at a still younger age caused a steep rise in killing of hens and chickens in the early thirties. The difficulty in finding a satisfactory market for the killed poultry resulted in foundation of four co-operative poultry slaughterhouses in 1932-34, two in Jutland, one on Fyn, and one on Zealand, so that any poultry breeder in Denmark could become a member and deliver his poultry to a co-operative poultry slaughterhouse.

The establishment of these slaughterhouses, which coincided with the foundation of a number of rather small private slaughterhouses, resulted in killing nearly all poultry for marketing in a few slaughterhouses. In consequence of this centralization, Denmark's imports of poultry stopped, and a considerable export was created. About 90 percent of the export went to Germany, but, although a great deal of poultry was frozen in that country, a considerably lower maximum price was fixed for frozen than for fresh poultry. This lessened the advantage of refrigerating poultry for that market. By selling on the home market — where before the war half of the poultry killed in

[11]Based on a paper presented by A. T. Jorgensen.

Danish slaughterhouses was sold — the advantages of freezing could be taken into account. But it took some years for the Danish population to recognize that frozen poultry is almost as good as fresh. This was partly because the first freezing experiments were unsuccessful. the poultry had been kept under bad conditions for some time before refrigeration, which was done at too high a temperature. The cold storage space available at that time was not constructed to freeze at a lower temperature than —10° C. This temperature was particularly unsatisfactory for freezing ducks and geese. One experiment showed that the fat turned so rancid in a few months that the poultry was almost unedible, whereas hens, chickens, and turkeys stored at the same temperature were all right.

Danish poultry freezing plants now freeze at a temperature of —25° C., whereas storage rooms are kept at a constant temperature of —18° C. All poultry (including ducks and geese) can be stored at these temperatures for many months without deterioration.

The chilling of the poultry is done at a temperature of 0° to —3° C. Hens and chickens are placed on shelves on wooden racks, the breast against the shelves so that breast and legs acquire an attractive shape before packing. Ducks and geese, on the other hand, are suspended in forks by their necks, so that the intestines sink into the belly. This gives them the shape desired by the consumers in Denmark, where practically all the ducks and geese are sold.

All poultry must be transferred for chilling as soon as possible after killing, especially in summer. Chilling is done by a current of cold air. When, in the course of a few hours the carcasses are nearly cool, they are moved into another chilling room, which has no forced air circulation. The poultry is packed 12 to 24 hours after killing. A considerable part of the poultry is sold in Copenhagen unfrozen, but since the killing is, to a large extent, seasonal, much is also frozen for later sale on the home and export market. Sales to importing countries are not constant, because of their domestic production and because of the difficult trading conditions. Before the war Germany and the United Kingdom were the principal buyers of Danish poultry, but no possibilities have existed since the war for export to these countries.

The present uncertain markets, because of their distance, necessitate careful handling of poultry before shipping. Most of the poultry so far has been sold without drawing, but in exporting to Switzerland, hens, chickens, and turkeys have to be drawn in order to meet government requirements. An increasing number of countries want to buy drawn poultry. Drawing involves a loss in weight of about 10 percent, but because a 10 percent higher price cannot be obtained, no definite plans for the production of drawn poultry have been made up.

Workers in Denmark are aware that poultry in the United States of America is often disjointed and marketed so that consumers can either buy the complete disjointed bird or only parts, such as breasts, wings, or thighs. A few years ago there was an attempt to sell eviscerated chickens in Copenhagen, but it failed. Disjointed poultry most likely will be still more difficult to sell than eviscerated poultry — most Danish housewives feel that a chicken should be fried without being cut in order to avoid losing flavor and juiciness.

It is possible that, among other things, lack of domestic help will alter the position in future. In that event, Danish refrigerating methods perhaps will have to be altered, but as long as poultry is more expensive than other meat and, therefore, not used very often, an important business in disjointed poultry can hardly be expected in Denmark.

## MISCELLANEOUS FROZEN PRODUCTS[12]

### Grape Juice

Grape juice, one of the important juices produced in the United States of America, is also one of considered importance in various countries of Europe, especially Switzerland and Germany. Grapes of the *Labrusca* type, used for juice in the United States, are quite different from *Vinifera* grapes grown in Europe.

The first step in juice-making, by both the old and the new methods, is to heat the grapes to free the juice and to extract the color from the skins. After the grapes are pressed, it is necessary to eliminate the argols or tartrates; otherwise the juice is muddy and harsh. According to old process, the grape juice, while still very hot, is put into large carboys and held in a cold cellar for at least three months, but usually for six or nine months. During that period, the argols precipitate, after which the grape juice is carefully siphoned off and reheated to 82° C. Then it is run into bottles, which are filled completely and closed with crowns.

By the new process, the freshly pressed juice is run into a large tank in an insulated room. As a rule, there is a refrigerated coil in the room and one in the tank. Brine is run through the coils and the juice is frozen into slush (—5° to —10° C.). In about a month or six weeks the argols are precipitated. Then the juice is allowed to thaw out slowly. When it reaches a temperature slightly above freezing, it is siphoned off from the sludge on the bottom. The juice is then flash-pasteurized by passing it through a heat exchanger.

[12]Based on a paper presented by D. K. Tressler.

as in the old process, and run into bottles, filling them completely full and closing them with crowns. A temperature of 82° C. substantially sterilizes the juices, but it does not kill all the molds. However, if bottles and jars are filled full, there is not sufficient air to permit the growth of molds. This new process eliminates the need for a large number of carboys to hold the juice during storage, and greatly hastens the juice-making process.

### Orange Juice

Large quantities of orange juice are frozen in the United States of America which grows a tremendous amount of citrus fruit, especially oranges and grapefruit. Most of the oranges are grown in Florida, California, Texas, Arizona, and a few other states. Thousands of carloads are transported to the north. In November and December and in the summer oranges are expensive, in midwinter they are cheap. Because of the price difference and because of the advantage of transporting a relatively small weight in a compact container, the freezing of orange juice has attained considerable importance.

Orange juice is one of the easiest substances to oxidize, and oxidation gives it a peculiar flavor. The United States has so many fine-quality oranges that the public will not buy orange juice with an oxidized taste. Orange juice is canned by a process similar to that for bottling grape juice, but the can or bottle must be kept in refrigeration, not because of spoilage by micro-organism, but to prevent objectionable changes which occur in the juice during storage at temperatures of 15° C. or higher.

Frozen orange juice is a splendid product when packed in hermetically sealed containers. They must be resistant to the action of citric acid, which is contained in all citrus juices. The juice should be frozen rapidly so that small crystals of ice are formed in it. This prevents all the pulp from settling to the bottom when the juice is thawed. One of the best machines for freezing orange juice is the Finnegan tubular immersion freezer, which has an outer shell and an inner tube. The outer shell contains alcohol at −25° or −30° C. Hermetically sealed cans of orange juice are fed into the tube, rotating as they drop through it. At that temperature the juice freezes rapidly. This system provides rapidly frozen orange juice of very good quality if careful chemical control is maintained.

Until about 1944 or 1945, orange juice was frozen without concentration. A new industry has arisen—the freezing of orange concentrate.

Much orange juice is concentrated either by vacuum evaporation at a temperature not exceeding 60° C. or by freezing the juice, then

breaking up the blocks of frozen juice and centrifuging the resultant slush to obtain the concentrate, or pressing out the concentrate. This produces a concentrate with 55 to 60 percent of soluble solids, which does not freeze to a hard brick. The great disadvantage of ordinary frozen juice is that the housewife has about as much trouble thawing the juice as she has in squeezing the oranges. As a rule, the price of ordinary frozen juice and fresh oranges are about the same, so she buys the fresh oranges because she does not like thawing the juice. But, if the frozen concentrate is used, it is not necessary to thaw it beforehand. It is merely put into a pitcher, three volumes of cold water are added, and, after stirring or pouring over, it is ready to serve. Since the concentrate is a slush, it dissolves quickly in water. This concentrate is very largely replacing the ordinary frozen orange juice. Since most of the oranges in the United States are transported 1,000 to 3,000 miles, there is a significant saving in freight costs. This saving is sufficient to pay for the evaporation and processing, and the concentrate can still be sold to the public at a somewhat lower price than ordinary orange juice.

### *Fruit Purées*

There is a considerable business in the United States of America in making a fruit product called a "purée." It is made by putting fruit through a sieve to remove and eliminate large seeds, seed cells, coarse fibers, and skin. The product is the same as that used in Europe to make jam; in the United States it is used to make fruit butters. A great quantity of these purées is also used in flavoring ice cream.

Some fruits, for example raspberries, are, without preliminary treatment, forced through a sieve or screen. Other fruits, for example peaches and apricots, are heated just enough to soften the fruit before it is put through a sieve. Sugar, sugar and pectin, or sugar and gelatin are added, and then the product is frozen. Freezing is done in various ways, one of them by using a machine similar to the ice cream freezer with the beater arms omitted.

### *Cooked and Baked Goods*

Freezing of cooked foods has been done since 1930, but there was no great business in it in the United States of America until about 1942. During the war, frozen cooked foods became very popular. Because of rationing, the shortage of tin plate, and other reasons, some products ordinarily sold in cans practically disappeared from the market. Frozen cooked foods replaced scarce canned foods, but, unfortunately, the price of these frozen products rose. There are many reasons for these high prices:

In the first place, cooked food requires a better container than raw food.

Secondly, most cooked food requires considerable labor, most of which must be done by experts at good wages. Consequently, the cost of these foods, in many instances, is out of the reach of the ordinary laboring man. After the war, when fresh food became available in unlimited quantities, people bought less frozen cooked foods, but there still is a fairly good sale of many items. One reason is that many women work in offices and factories in the United States and have little time to prepare meals with fresh food. Prices have dropped a little on the products most in demand, for instance, French fried potatoes, which are very popular. Housewives do not like the work of preparing potatoes; the frying causes a smell in the house, and smoke from the cooking fat deposits on the walls. She can reheat frozen cooked potatoes in fifteen minutes and save time and work. Perhaps they are not quite so good as the best fresh French fried potatoes, but they may be as good as those cooked by the average housewife.

A few of the many cooked foods being frozen in the United States include: hors d'oeuvres, canapés, sandwiches, soups, cooked meats and meat dishes such as veal loaf, meat loaf, beef stew, veal stew, chile con carne, corned beef hash, roast beef hash, stuffed peppers, veal cutlets, steak, chicken á la king, creamed chicken, fried chicken, chicken pie, chicken giblets and rice, roast duck, turkey hash, meat pies of various kinds, codfish cakes, fish chowder, creamed tuna, creamed salmon, salmon loaf, clam chowder, oyster stew, shrimp sandwich spread, lobster stew, lobster Newberg, baked beans, lima beans baked with ham, meat balls and spaghetti, macaroni and cheese, Welsh rarebit, chop suey, giblet gravy, fruit salad, fruit cocktail, various bakery products, and potatoes.

The most popular of all these items is potatoes; production goes into millions of pounds. If sliced potatoes are frozen and then thawed, the result is a miserable black product no one would eat. But, if they are scalded to inactivate enzymes, potatoes can be frozen without discoloration. Some are frozen without being cooked. They are peeled and washed simultaneously by machinery, then they are cut automatically and steamed long enough to heat them up to 90° C. They are cooled by fan, air, or ice water. Then they are packaged in moisture-vapor-proof packages and frozen. That is the process for freezing raw potatoes—they are slightly cooked but still taste raw.

The process for preparing French fried potatoes is pretty much the same at the start. The potatoes are peeled, washed, and cut mechanically. After this, they pass automatically on a conveyer belt to a steam chamber where they are heated about two minutes to

inactivate the enzymes. Then they are dried by air currents. The potatoes are automatically emptied into a deep fry-bath, which is usually heated electrically at a carefully controlled temperature. At the end of the frying operation, they are usually heated to a slightly higher temperature to get the desired brown color. Then they are conveyed by another belt for about 20 feet (6.09 m.) to allow the fat to drain off. This belt is brilliantly lighted for inspection. The potatoes are emptied into a packaging machine, which fills, closes, and seals the packages.

It is important that potatoes are uniform in color and flavor.

Potatoes have to be stored at a uniform temperature of about 4.5° C. in order to maintain the sugar content at a uniform level. Potatoes stored at temperatures under 4.5° C. build up their sugar because of too little respiration. At temperatures above 4.5° C., the sugar is used up and the potatoes become too dry. If they have been stored at a temperature lower than 4.5° C. they can be greatly improved for culinary purposes by allowing them to remain at about 15° C. for two or three weeks. In commercial freezing operations, a chemist should be on the job to watch the relationship between sugar and starch content.

One very popular potato product, better frozen than fresh, is known as "puffs." They are prepared by mixing mashed potatoes with egg and a little sweet potato. The mashed potatoes are extruded like a doughnut and dropped into hot fat; they puff up as they cook. A process of freezing mashed potatoes has also been perfected.

A long list of cooked foods is now frozen commercially in the United States, but it would not be advisable for any European restaurant, hotel, or commercial enterprise to go into the business of freezing any of them without a long period of experimentation. In Europe the methods would have to be different from those in the United States of America in order to get the flavor, texture, and quality desired in cooked foods. One important line of research in the Birdseye Laboratories between 1929 and 1933 was the freezing of cooked food. That research cost a great deal of money. Before going into the business, much research and pilot plant work must be done, followed by a gradual increase in the scale of operations. The product offered must be as good as the housewife can produce and capable of standing up under six months' storage. In many laboratories no product is considered satisfactory until it will stand storage for at least a year.

There are difficulties with gravies, sauces, and particularly jellied foods: freezing tends to coagulate the colloidal condition of these products. Other ingredients must be added to, or substracted from, the recipes. Contrary to what may be expected, fats turn rancid

rather rapidly in cooked foods. Cereals in a formula may act as antioxidants and prevent rancidity. In cooking green vegetables the chlorophyll is altered, often becoming a dirty gray, a condition that is exaggerated during freezing and storage. Frozen fully-cooked vegetables look like canned vegetables. The buyer expects to find something equivalent to fresh products, not canned.

During the war, cooked foods frozen on the plates were reheated and served. They are now used to a great extent for United States aircrews and passengers. This has proved an excellent way of supplying these people with meals of good quality. The product is fairly good, but the prices are high because it includes the cost of trays and paper, labor, etc. The housewife must still pay as much for these assembled meals as for a meal in a restaurant.

Cooked food plants must be sanitary. This is very important. If these foods are contaminated during handling, there may be trouble. In Chapter 7 it is pointed out that cooked food should be packed hot. This is all right if it is rapidly cooled, but in general it is easier to cool before packaging than after. Beware of the cooling problems, especially with very viscous foods.

The general use of home freezers has caused an increase in the sale of commercially frozen foods. Once familiar with the use of frozen foods, housewives buy more from their grocers. Some housewives have the goods delivered at their home. One company rents frozen food cabinets at a low cost and then delivers frozen food once a week. Persons who own home freezers use about twice as much ice cream as those who do not. When ice cream is always available in the home kitchen, much more is used.

## *Bakery Products*

Freezing of baked goods is not new. Eastern Quebec (Canada) is a very isolated region, rather barren, and very cold, and the people are isolated from the rest of the country. Because of that, they live pretty much as they did in 1800. They freeze their bread in the late autumn for use in winter, and have been doing this for centuries.

Bread has been frozen by modern methods and held for a year at $-18°$ C. At the end of that time, it was equivalent in freshness to day-old bread. Another development is to make yeast rolls, put them into paperboard containers for freezing, and sell them to the housewives. It takes less time to bake the frozen rolls than to turn out fresh bread. Two or three times as much yeast must be used when freezing.

Most cake batters and pies freeze very well. Pies can be frozen either before or after baking. As a rule, the most popular are those frozen before they are baked. After freezing they are wrapped

in moisture-proof cellophane, put in a package and placed in storage. Deep-dish (single crust) pies are also frozen in shallow containers made of heavy aluminum foil. It is very difficult to tell the difference between freshly baked pies and those frozen about six months previously and then baked. Peaches and apples, however, require special treatment if they are to be used in pies which are to be stored for a long time.

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# 11. Transportation of Chilled and Frozen Foods in Europe[1]

FROZEN BEEF was the first commodity which required refrigerated railway transport in Europe at temperatures below freezing. At first ice was used to eliminate the heat-flow from outside, but it was soon found that a considerable amount of salt had to be mixed in, which caused the ice to melt very rapidly. If little or no salt was used, the result was that the colder beef absorbed heat, both from heat-flow from outside and from the ice.

Another difficulty was that the colder beef attracted moisture from the melting ice, and mold developed on long journeys. Even after comparatively short journeys, followed by re-storing inland, mold was nearly always unavoidable. It took some time before shippers realized that the use of ice for transport was not only an unnecessary expense, but often did more damage than good.

## THE "A" TRUCK

At present the so-called "A" truck (refrigerator car) for the transport of frozen beef is considered the best. It is a two-axled car with no facilities except a perfectly closed box, insulated with 10 or 12 cm. of cork or peat, and with a loading capacity of at least 15 tons of frozen beef. By leaving out the ice-container and the hanging bars for chilled meat, it was possible with a two-axled car to get a ratio of 1:1 between weight of car and loading capacity. The heat-flow of this car is never more than 1,400 calories per 1° C. difference over 24 hours.

[1]Based on a paper presented by H. J. Jerne.

This type of car is mostly used for perishable goods, which at loading have a temperature of at least —8° C., and which either move directly into consumption or after a short journey are again put in low temperature storage.

The difficulty in using a standard refrigerator car for transporting fresh-killed meat from one center in Europe to another over unprecedented distances, was mainly that fresh-killed meat, not cooled before transport, requires quite different facilities than chilled meat. Uncertainty as to whether the slaughter-house had facilities for cooling made it necessary to have cars which could be used in both situations.

## THE STANDARD REFRIGERATOR CAR

Facilities for both purposes were embodied in a standard refrigerator car first constructed for the Danish State Railway, but ignorance in handling the car caused much damage during transport.

Fresh-killed animals on the continent are often loaded into the car immediately or very shortly after being killed. For such meat it is necessary to have a constant draft of outside air blowing through the car to carry off the animal heat of the carcasses. This constant draft keeps the carcasses dry and makes it more difficult for bacteria to multiply. When the car is used for such transport, it is necessary to keep the ventilators on both sides wide open; the openings are covered with an air filter. The insulated walls of the car then act as a heat-protecting cover against the sun. If such a flow of air is not allowed, and the car is closed and ice is used to cool the meat during transport, the carcasses became slimy and very quickly deteriorate.

When the killed animals have been cooled down to about —2° C. before loading, the ventilators are closed, the ice container is filled, and eventually a small percentage of salt is added to counteract the heat flow through the walls.

For transporting fresh meat, a three-axled car is used, which with ice-container and hanging arrangements still maintain a ratio of 1:1 between its weight and loading capacity. This car is constructed on the principles already described. The heat flow from outside, when the car is closed, is about 1,400 calories per 1° C. difference in 24 hours. To avoid mistakes in handling this car for different purposes, the facilities open and close by turning a handle outside the car.

The intermediate wall between the ice container and the interior of the car is made in sections like doors. These doors as well as the ventilators open and close by the same handle. After turning the

handle to the desired position, the handlebar is locked to assure that nothing can be altered during transport.

Long journeys and frequent delays at national borders for customs formalities indicated the necessity for a car with mechanical refrigeration. At first a compressor system was used, with power obtained from the axle of the car. Because of the difficulty of obtaining water when the car was running, and because of the difficulty of obtaining electric current when the car stood still or was shunting about, this system was never popular.

Notwithstanding the difficulties of using mechanical devices for cooling, it became more and more necessary, especially for transport from the Balkans where hardly any cold-stores or ice-factories existed, to find ways to cool the goods and to cool the cars before loading.

## THE REFRIGERATED TRAIN

These difficulties were solved by constructing a refrigerated train, consisting of one car containing a compressor driven by a crude-oil engine and having a water-tank for cooling water coupled to six or eight insulated cars. The cars are cooled either by cold air driven by a strong ventilator from the machine car or by brine pumped from the machine-car. The cost of running these trains is considerable since each train requires two engineers. Consequently these trains are used only for large loads of 100 to 120 metric tons.

To transport fruit from Italy to various North European countries, a two-axled standard car was introduced with an ice container and fitted with a strong ventilator driven from the axle of the car.

## THE DYNAMO-VENTILATOR CAR

Out of this experiment evolved a new construction, called the Dynamo-Ventilator car mainly used for the transport of fresh meat and fruit. It is a two-axled car with a 10 cm. cork insulation, a floor space of 23.42 meters, and 18 hanging bars with 12 hooks each. The bars and hooks are made of new light metal and the ice container holds 1,800 kg. of ice. The ratio of car weight and load is 1:1.

In this car an electrically driven ventilator draws the warm and moist air from the loading space through a duct that runs along the ceiling. From the duct the air goes down through the ice, leaving the ice-bunker at the bottom through an opening in the insulated partition wall, and enters the loading space cooled and dried.

The car is well insulated and air-tight. The strong air circula-

tion prevents the moisture from depositing on the goods, and undue shrinkage is prevented by maintaining a fairly high relative humidity without the risk of mold or deterioration. The temperature obtained is $-2°$ to $+3°$ C. with a relative humidity in summer of about 85 percent.

The ventilator is driven by a dynamo connected to a battery, which keeps it running continuously during the transport period, whether the car is moving or stationary. The dynamo is driven by the car axle. The construction of the battery, the dynamo, and the fan is such that after the car has run four to five hours, the battery is charged sufficiently to drive the fan for 60 hours.

The system works automatically and is often used by railway companies for lighting passenger trains. It requires no attention or safeguards and accords with the different railway regulations. In the air-duct under the ceiling, against the opposite end of the ice-bunker, are two Flettner rotors as a safeguard in case of breakdown of the fan system. The cost of running such a car is hardly higher than that of running an ordinary refrigerator car cooled with ice, and is much lower than running a mechanically cooled car.

## THE ROLLING COLD-STORE

To facilitate the distribution of frozen goods in small towns and villages, and to share the benefits of refrigeration with farmers of the various food-producing countries, a car was constructed that could be left on the siding at any small station in a rural area, either for distribution or as a cold store in which fruit and vegetables gathered in the vicinity could be cooled and transported.

*Figure 71. The "Rolling Cold Store."*

The car constructed for this purpose is a three-axle car with an antechamber in the middle (Figure 71) and two compartments at either end capable of holding about 9 metric tons each. The cooling medium is ammonia in an absorption system. This car, generally known as "The Rolling Cold-Store" was later fitted with a silica-gel system, but the necessary permission from the railway authorities to use propane gas for heating was never obtained.

To be able to run the refrigerated load without transfer from the continent on a ferry-boat to England, a special car was built by the Altec Company on principles described above, so constructed as to be capable of running on continental as well as on English rails. The weight of this car, including machinery, water-filling, and oil supply, is about 32,000 kg., and the load capacity is about 25,000 kg. It is cooled by an ammonia compressor, driven by an electric motor supplied from a dynamo driven by a Diesel engine, and regulated by a thermostatic arrangement, which controls the temperature of the load compartment.

The development of quick freezing, especially of fruit and vegetables, brought new problems to refrigerated transport. Temperatures much lower than before had to be maintained even over shorter transport distances and smaller units than a railway car were needed. To meet this need, container units were constructed on the same principles as a truck body with a load capacity of about 2 or 3 metric tons. The containers are on flanged wheels and can be run off loading platforms onto a motor truck with rails sunk into the floor or they can be run onto a four-axled flat car with rails fitted crosswise on the floor. A locking arrangement keeps the containers fastened during transport. Seven units are carried on a railway flat car, the middle one being the machine unit for refrigeration, connected to the three units on either end. In the machine-unit is a 40 horsepower Diesel engine which, through a dynamo, supplies power to four electric motors, each running a compressor of 6,500 cal/hr. Four ventilators, each of ¼ h.p., circulate the air through the six containers. Temperature can be maintained at 20° C.

The difficulty was that very few motor trucks fitted with rails were available in the provinces, and at many places no crane existed capable of lifting the container from the railway car to an ordinary motor-truck. It was therefore decided to rebuild some of these cars, somewhat on the order of the "rolling cold-store" cars, with the machine unit in the middle and two compartments at each end, as illustrated in Figure 72. The loading capacity was thereby raised to 20 or 30 metric tons, depending on the nature of the goods. The machines work automatically. In the machine unit is a sleeping berth for an engineer, who has to accompany the car on its journey. Naturally, transport in such a car is somewhat expensive.

Water ice and salt, on account of their weight and volume, could not be used in such small units, and attention was drawn to dry ice as a possible cooling medium.

The temperature of the dry ice is —80° C. It sublimes directly from solid carbon dioxide to the gaseous form (500 l kg.), thereby absorbing 153 cal/kg. Sublimation is very slow, taking 20 to 25 hours for a 10-kilogram piece to evaporate. It was learned gradually, that dry ice could be used to maintain all temperatures from above 0° C. and down to —20° to —25° C., if applied in different ways.

## *REFRIGERATED TRUCKS*

The desire to transport frozen products over short distances brought about the construction of refrigerated motor trucks. The body of these trucks was constructed on principles similar to the car bodies, but instead of cork, 10 cm. of kapok was used for insulation; this seems more suitable when dry ice is used as a refrigerant.

In one of these truck bodies a dry ice container is placed under the ceiling of the roof, the floor of the dry ice container being an aluminium plate about 2 cm. thick on which the dry ice is placed. At one end of this container a wire netting allows the carbon dioxide gas to enter the load compartment. In another, there is an insulated room at the back of the truck body in which the dry ice container is placed. The top and bottom of this room are connected with the load compartment, and three Flettner rotors sunk into a ceiling air-duct takes care of the circulation. The gas is thus prevented from entering the load compartment.

*Figure 72. Refrigerator car with two compartments at each end and refrigerating unit in the middle.*

Autotruck haulage of perishable goods under refrigeration, even over long distances, has been developing considerably in recent years. Autotruck bodies are built on the same principles already discussed for railway car bodies.

At first dry ice was used for transport by hanging it in sacks from the ceiling, or placed in small bunkers inside the load compartment. This, however, is an inefficient way to use dry ice and it does not guarantee safe transport of frozen products. It would be more efficient to construct the railway cars or autotrucks on the same principles described for standard car bodies, with a more effective dry ice cooling arrangement.

There must be a dry ice container, well insulated from the load compartment. For actual cooling of the load compartment there should be a secondary refrigerant, or brine, circulating through finned coils extending around or over the load compartment. The refrigerant should run through the dry ice bunker, to cool it. Temperatures in the cooling coils of the load compartment can be regulated by a thermostatic valve, to control the flow of the secondary refrigerant.

One of the greatest difficulties with dry ice as a transport cooling medium is its distribution from the factory to the customers, for it is uneconomical to maintain a stock at various depots.

World War II created havoc with the refrigerated railway cars on the continent, most of them having been destroyed or damaged. New cars must be built, and it is to be hoped that the experience gained in the past may be fully utilized in the future when the restoration of Europe will necessitate the construction of new conveyances to meet the requirements of safe transport of perishable goods.

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# 12. Marketing Frozen Foods in Europe[1]

THE MAIN PURPOSE of freezing food is to preserve products during the harvest season and to keep them fresh and nutritious for consumption when fresh supplies are low.

European production of frozen food, other than fish, for international trade is still quite small and scattered. In Europe, meat, poultry, and eggs are frozen or chilled mainly for domestic consumption; commercial freezing of fruits and vegetables is still small.

## *TECHNOLOGY OF MARKETING*

Some of the more important features of the technology of marketing are: (1) production, quality, packing, and storage; (2) transport, trade and exchange problems, distribution; (3) prices and payments. Among these features each product will find its place, but the marketing of all frozen foods is closely related. How each product or group of products may need one another on the march to the consumer is illustrated by the example of meat, poultry, and some fishery products, which may need to bear a greater part of transport costs than, for example, vegetables.

The system of marketing differs widely in various countries and for different foods. Frozen food may be bought and sold freely between countries, or its movement may be restricted by trade agreements, exchange regulations, etc. The food trade in some countries may be handled by private producers and businessmen, in others by producers' organizations, co-operatives, or government agencies.

[1]Based on a paper presented by N. Jangaard.

Those concerned with marketing must acquaint themselves with such problems and decide how to tackle them. However, the marketing possibilities for frozen fresh food and the steps necessary to introduce frozen food in European markets are indicated here.

Frozen food is a relatively new produce in the world. New methods of freezing food and keeping it in the most nutritious and attractive way are continually being developed. The freezing industry is still pioneering in this new and important field. Packers of frozen foods and distributors of chilled and frozen food are also in the pioneering stage. Like all pioneers, they face difficulties of various kinds.

It may be asked if it is worthwhile to spend so much time and energy on introducing this new method of food preservation, on marketing frozen food, and on teaching people how to cook frozen food. Known and proven ways of preserving food, such as salting and drying are easy to use and cost less than freezing. There is a well-developed canning industry which is processing foods of many kinds into well-preserved and nicely packed jars, cans, and bottles. Why not expand these ways of food preservation, instead of introducing a costly new method which needs pioneering and tremendous effort in processing and marketing?

Farmers, fruit and vegetable growers, and fishermen, know the answer to this question, for farmers and fruit growers are well aware that these processes cannot take off their hands all the crops of their farms and orchards at satisfactory prices during the short harvesting season and fishermen know that these industries cannot take care of their catches as rapidly as necessary, so they can make new catches and increase production.

To a large extent, preservation by salting and drying are only subsidiary processes, using supplies which cannot be sold fresh or canned. And, the return from these processes is less than for food consumed fresh or sold to canning factories. Consequently, these methods alone are not satisfactory to the producers.

The freezing industry should relieve the farmer and the fisherman, give him a better reward for his products, encourage him to produce more. Food freezing will not eliminate other food preservation methods. Canning will certainly continue to develop and at least to hold its own. Dried fruits and vegetables, salted and dried fish will keep their own markets. The conservation of food by freezing will greatly assist in the *balance* of production, enabling the producer to divert crops to those processes which are most suitable and remunerative for him. The development of food freezing will also enable the farmer and the fisherman to produce more, and it will inspire him to produce a greater variety of products which are suitable for freezing.

Other technical improvements have greatly served the expansion of agriculture and fisheries. Agriculture has greatly benefited from the tremendous expansion in farm tractors and harvesting machines. fisheries have been assisted by the advent of the Diesel motor, auxiliary machinery, and tanks for live bait. Refrigerated railway cars, motor trucks, and containers for transport are important developments. All of these technical developments have a bearing on marketing and provide an approach to marketing problems.

Marketing technology is the basic starting point for a marketing survey. Any change in technique immediately affects other phases of marketing. A change in production, in freezing, in packaging, or in transport, may have an impact on other aspects of the marketing scheme, such as price calculations of raw materials and finished products. Technical alterations may even change the direction of flow of goods.

Restriction of trade by agreements and exchange regulations both influence international trade, and therefore become part of the technique of marketing. A study of these technical problems in the marketing of frozen foods shows why marketing is difficult and why it is pioneer work for producer as well as distributor.

## THE IMPORTANCE OF QUALITY

For high-quality frozen foods it is an absolute necessity that only *strictly fresh* products be frozen. This holds for fishery products and agricultural products, and should be obvious. It is mentioned because there may be some temptation to freeze products which are not strictly fresh and because it may be difficult to detect the quality defects in a frozen product which could be seen in the raw material. However, when such products reach the consumer and are thawed for cooking and eating, the defects are sure to appear. This is damaging to the trade in frozen food. It often ruins the efforts made to introduce frozen food to the consumer. It is one of the principal stumbling blocks in the marketing of frozen food.

After it becomes stale, fresh food does not recover its freshness by refrigeration. Deterioration may be arrested by chilling and freezing, but it will appear again, either at the same stage or in a more advanced form, when the food is thawed. The degree of deterioration depends on storage, transport, distribution, and other conditions. This is of particular importance in freezing fish, but it should also be kept in mind for fruits and vegetables.

Those in charge of marketing frozen foods, whether producers, sellers through co-operatives, or commercial firms, must be sure that they are introducing to the market a strictly fresh product, and

must be able to convey their assurance to the buyers. This is the first *must* in the marketing scheme for frozen food.

From that first sale, and until the frozen food reaches the consumer's table, it can have rather rough sailing. Other foods preserved by methods such as canning or dehydration may not concern the producer much once they have left his farm or production plant. Less perishable food may follow the ordinary course of trade, by-pass bottlenecks, and encounter the usual obstacles without burning the hands of the producer too much when something goes wrong. But it is not so with frozen food. The producer of fresh and frozen food needs to follow his products all the way to the consumer's table if he is to succeed in establishing a new and important market for his goods. This may frighten a producer of vegetables, fruit, or fish, in any country. He may ask: Why is it necessary to go to so much trouble? How could I possibly participate in such a complicated arrangement?

The first and perhaps the most understandable reason for developing the preservation of perishable foodstuffs by refrigeration is the improvement of marketing for the benefit of the producer. Average yields per hectare of many products are about on the same high level in the United States of America and in Western Europe, but farm incomes are considerably higher in the first named country. Doubtless, then, if the marketing of these products in Europe were equally developed, better returns from the land would result, thus giving a better income to the producer and a better living for the people. There is another reason why the producer must be unusually active in this field: If frozen food is not handled properly, if it reaches the consumer in bad condition, it slaps right back to the packer. With many other kinds of preserved foods, a bad product may only cause the consumer to change the brand. But, if the consumer gets a bad frozen product, he may blame it all on the fact that it is frozen, and may never want to buy frozen food again. This hurts not only the individual packer, but the entire frozen food industry.

## MARKETING DIFFICULTIES

The pioneers of frozen foods have had a hard struggle with the unwillingness of the consumer to accept frozen food as the equal of fresh unfrozen food. The backbone of this consumer resistance has been broken in countries where the frozen food industry is most advanced. It is necessary to overcome this resistance in Europe. This is part of the marketing problem of frozen food.

How can a producer take his part in the complicated marketing

of frozen food? It may not be possible or advisable to market frozen perishable products in the same way as nonperishable products, since the latter can be more easily handled by the trade than frozen perishable food. Fresh products may have to be brought from farms and orchards, or from small fishing ports and islands to processing plants and shipping centers by special transport. They have to be sold in lots big enough to fill refrigerator cars and trucks. They have to be stored in sizable quantities, both at the processing and at the receiving centers. For these and other reasons the producer should follow the goods until they reach the ultimate consumer.

Because of the special character of frozen food it cannot be expected that private trade will be very active in organizing its marketing in Europe. But private trade will naturally have an important part to play in various phases of distribution. This part of the marketing problem has been and is being studied in the United States, the most advanced country in the field of frozen food. Conditions there, are, however, different from those in Europe. In that country there is free travel from state to state and trade with all states without the trouble faced in Europe when crossing borders. They have therefore developed different ways of trade, and can more easily reach markets. Nevertheless, they have found that frozen foods must be channeled direct from producer to consumer. This is done, for example, by agreement between producers and large chain stores, which reach consumers all over the country and have financial means for large-scale organization of distribution.

There is no chain-store system covering the whole of Europe, and it may be necessary to establish intra-European distribution of frozen perishable food within the complicated framework of differing customs and trade policies. There is, however, no difference of opinion among European nations as to the necessity for all to raise production and consumption of perishable foods. Being all in the same hemisphere, and harvesting their crops practically at the same time, the possibilities of selling their products fresh during the harvesting season are poor. They must, therefore, look for new preservation methods, and chilling and freezing are becoming of more importance.

## Distribution among Countries

Distribution among European countries is a vital feature of marketing frozen food. A system must be established that can bring the food quickly and safely across borders from the producer to the consumer. Such a system will require well organized action. Producers must jointly collect their crops for freezing, and build freezing plants and cold stores, or enter into agreements to this end with private enterprise. It seems equally necessary for administrators of

freezing and storage plants in the various countries to co-operate in the maintaining of quality and stocks processed and ready for marketing.

Those in charge of marketing frozen food must co-operate with marketing organizations in other countries in order to avoid the glutting of markets and consequent waste. When the main purpose of preserving fresh food during seasons of high production is to store it for marketing at more suitable times it would be meaningless not to control sales. Co-operation with and among railway companies and other transport organizations will be necessary for safe refrigerated transport. Processors must establish co-operation with organizations in the various countries for a safe and sound system of retail distribution.

Such a system of co-operative effort may seem Utopian, and its realization in this troubled world may seem impossible. But it needs immediate study and preparation, for producers are being encouraged—now—to adapt their pattern of production to the standards necessary for the preservation of food by cold.

During the relatively short time that the frozen food industry has existed in North America, about 90 percent of all its troubles have arisen from distribution. Now the industry is seeking closer co-operation with large retail organizations, for better distribution. Europe, having learned from the North American experience, should develop its own system, based on European background, problems, and preferences.

## PRICES

In general, the price of frozen food is still higher than, for instance, canned food. Prices of some frozen foods are higher than those of fresh products. Frozen fish, poultry, and meats, are exceptions: they commonly sell at the same or a lower price than comparable fresh products. It is evident that prices of many frozen foods are too high, and price is one of the main obstacles to increased consumption.

When cost of processing, storing, transport, and distribution are taken into consideration, it is clear that frozen food must be expensive. However, it need not be so expensive as it is. There is no reason why it should not be sold as cheaply as canned food. To reduce prices, production and marketing must be rationalized. Greater production, if not mass production, will materially reduce the cost of production. Greater quantities to be frozen and stored will force the industry to make more efficient use of machinery and storage space, resulting in lower handling costs and lower prices. Greater quantities for transport will reduce transportation costs.

These improvements can be introduced by the producers themselves. It has been proved in North America, that increase of production followed by increase of consumption has reduced prices of frozen foods considerably; they are now coming into line with canned and fresh food.

Technical development in food freezing will help to reduce the cost of production. Scientists and technical people are constantly working on new processes and developments in freezing food, and on new and better methods of utilizing offal and waste. Specialists are busy in the marketing and distribution field to help develop better methods of transport, thawing, and cooking of frozen foods. Electronics and other new inventions are already in use for freezing food, and in defrosting. It has been found that by high frequency dielectric heating, a kilogram of frozen fruit can be defrosted in three or four minutes as compared with the three or four hours ordinarily required.

## NEED FOR CO-OPERATION

All this work must be done by organized effort if more and better food is to be produced for the good of all. The farmer and the fisherman, the scientist and the technician, the laborer and the tradesman, must work on it together. The time of the lone-hand player is past. The technology of production—of sowing and harvesting—the technology of industry—of freezing and packing—and the technology of marketing—of buying and selling—must be accompanied by the technology of co-operation and human relationships. This technology is far advanced in Europe, so the freezing and marketing of food should be fitted into the existing co-operative machinery.

For co-operation in the field of marketing, the Food and Agriculture Organization of the United Nations is ready to give all possible assistance. The main purpose of FAO is to help increase production and improve distribution of food. FAO is greatly interested in the better marketing of food and is aware of the importance of preservation of food by refrigeration. FAO has, therefore, taken up the work of improving this industry in its member countries. FAO has established co-operation with the Economic Commission for Europe for practical action on a number of pertinent problems, and on the problem of exchange and trade agreements for facilitating trade among European countries.

Until definite progress is achieved along these lines, European countries are not able to take full commercial advantage of developments in the freezing industry for intra-European trade. This may be particularly true of countries trading especially in fishery products. For the time being, these countries may have to tackle their marketing

problems on their own initiative and risk. The development of broader marketing schemes for frozen food will be more rapid if the agricultural countries of Europe establish a similarly developed freezing industry and cold-storage system for mutual exchange of frozen foods.

Meantime, studies should be made of available material from other countries, especially from the United States of America with regard to marketing frozen foods. Such material covers experience gained through many years of consumer resistance, technological developments in marketing, institutional use of frozen food, utilization of waste, price calculations, and related subjects.

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# CONVERSION FACTORS

Conversion factors shown below have been approved for the use of FAO by two international conferences on forest statistics, held in Washington and Rome in 1947.

These factors are averages, adopted by agreement. However, if any country considers that serious errors in the conversion of its statistics will arise through use of these standardized factors, FAO will be prepared to use specific factors recommended by that country in converting its statistics.

| | | | | | | |
|---|---|---|---|---|---|---|
| LENGTH | 1 millimeter | = 0.03937 in. | | 1 inch | = 25.40 mm. | |
| | 1 centimeter | = 0.3937 in. | | 1 inch | = 2.540 cm. | |
| | 1 meter | = 3.281 ft. | | 1 foot | = 0.3048 m. | |
| | 1 meter | = 1.094 yd. | | 1 yard | = 0.9144 m. | |
| | 1 kilometer | = 0.621 mile | | 1 mile | = 1.609 km. | |
| | 1 yard = 3 feet = 36 inches | | | 1 mile = 1,760 yards = 5,280 feet | | |
| AREA | 1 $cm^2$ | = 0.155 sq. in | | 1 sq. in. | = 6.452 $cm^2$ | |
| | 1 $m^2$ | = 10.76 sq. ft. | | 1 sq. ft. | = 0.0929 $m^2$ | |
| | 1 $km^2$ | = 0.3861 sq. mi. | | 1 sq. mi. | = 2.59 $km^2$ | |
| | 1 hectare | = 0.003861 sq. mi. | | 1 sq. mi. | = 259 ha. | |
| | 1 hectare | = 2.471 acres | | 1 acre | = 0.4047 ha. | |
| | 1 square kilometer = 100 hectares | | | 1 square mile = 640 acres | | |
| VOLUME | 1 $cm^3$ | = 0.061 cu. in. | | 1 cu. in. | = 16.39 $cm^3$ | |
| | 1 $m^3$ | = 35.31 cu. ft. | | 1 cu. ft. | = 0.02832 $m^3$ | |
| | 1 liter | = 61 cu. in. | | 1 cu. in. | = 0.01639 liter | |
| | 1 liter | = 0.2642 gal. (U.S.) | | 1 gal. (U.S.) | = 3.785 liters | |
| | 1 liter | = 0.2200 gal. (Imp.) | | 1 gal. (Imp.) | = 4.546 liters | |
| | 1 liter = 1,000 $cm^3$ | | | 1 gallon = 4 quarts | | |
| MASS | 1 gram | = 15.4324 grains | | 1 grain | = 0.64799 gram | |
| | 1 kilogram | = 2.205 pounds | | 1 pound | = 0.4536 kg. | |
| | 1 metric ton | = 1.102 short tons | | 1 short ton | = 0.9072 metric ton | |
| | 1 metric ton | = 0.9842 long tons | | 1 long ton | = 1.016 metric tons | |
| PRESSURE | 1 kg. per $m^2$ | = 0.2048 lb. per sq. ft. | | 1 lb. per sq. ft. | = 4.882 kg. per $m^2$ | |
| | 1 gm. per $cm^2$ | = 0.0142 lb. per sq. in. | | 1 lb. per sq. in. | = 70.31 gm. per $cm^2$ | |
| DENSITY | 1 kg. per $m^3$ | = 0.06243 cu. ft. | | 1 lb. per cu. ft. | = 16.02 kg. per $m^3$ | |

Inches, feet, yards, and miles are U.S.A.: British units.